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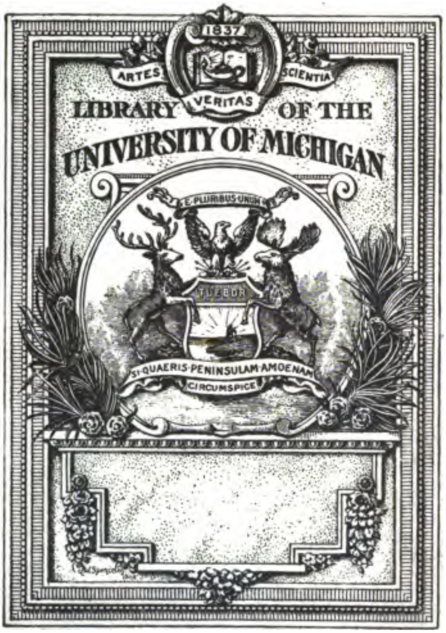
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PALÆONTOLOGY

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INVERTEBRATE

BY

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PREFACE TO THIRD EDITION.

THE general plan of this work is to give, in each group of the Invertebrata, first, a short account of its general zoological features with a more detailed description of the hard parts of the animals; secondly, its classification and the characters of the important genera, with remarks on the affinities of some forms; and thirdly, a description of the present distribution, and the geological range. The account of each genus is followed by the enumeration of one or more typical species, so as to guide the student in making use of a large collection.

In the present edition some parts of the book have been enlarged, and others modified, in accordance with the researches of recent writers, and as the outcome of further experience gained in teaching the subject since the second edition was issued. Descriptions of a somewhat larger number of genera are given, since it is believed that this will make the book more generally useful, while still retaining its elementary character.

The number of illustrations has been increased; but as before, they are employed mainly for the purpose of explaining structure and terminology, and will not enable the student to dispense with the use of actual specimens.

The list of palæontological works is intended to indicate to the student where he may obtain further information in any branch of the subject, but not to give a complete catalogue of even the more important works; it includes works of general interest in each group, and others dealing especially with British fossils.

My thanks are due to the Editor of the Series—Mr A. E. Shipley—for advice and help; and to Dr F. L. Kitchin for reading the proofs of the first half of the book.

H. WOODS.

ST JOHN'S COLLEGE, CAMBRIDGE.
October, 1902.

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The blocks from which Figs. 4, 6, 7, 11, 20, 32, 33, 123, 129, 133 and 138 are printed, are borrowed from Shipley and MacBride's *Zoology* (Camb. Nat. Science Manuals).

DIVISIONS OF THE STRATIFIED ROCKS.

Cainozoic or Tertiary.

- Pleistocene
  - Post-glacial deposits (river-gravels, cave-deposits, etc.)
  - Glacial deposits (Boulder Clay, etc.)
- Pliocene
  - Forest Bed Series
  - Norwich Crag Series
  - Red Crag
  - Coralline Crag
- Miocene (not found in England)
- Oligocene
  - Hamstead Beds
  - Bembridge Beds
  - Headon Beds
- Eocene
  - Bagshot, Barton, and Bracklesham Beds
  - London Clay
  - Oldhaven Beds
  - Woolwich and Reading Beds
  - Thanet Sands

Mesozoic or Secondary.

- Cretaceous
  - Upper
    - Chalk
    - Gault and Upper Greensand
  - Lower
    - Lower Greensand
    - Wealden
- Jurassic
  - Upper
    - Purbeckian
    - Portlandian
    - Kimeridgian
    - Corallian
    - Oxfordian (with Kellaways Rock)
  - Middle
    - Great Oolite Series (Bathonian)
      - Cornbrash
      - Forest Marble
      - Bradford Clay
      - Great Oolite
      - Stonesfield Slate
    - Inferior Oolite Series (Bajocian)
      - Fuller's Earth
      - Inferior Oolite
      - Passage beds (sands)
  - Lower
    - Lias
    - Rhætic Series (often placed in the Trias)

TRIASSIC	Keuper Series	
	Muschelkalk (not found in England)	
	Bunter Series	

Palæozoic or Primary.

PERMIAN	Magnesian Limestone Series	
	Sandstones, etc.	
CARBONIFEROUS	Upper...	Coal Measures
		Millstone Grit
	Lower...	Carboniferous Limestone Group
DEVONIAN AND OLD RED SANDSTONE	Upper	
	Middle	
	Lower	
SILURIAN	Downtonian Series	Downton Sandstone
		Upper Ludlow Beds
		Aymestry Limestone
		Leintwardine Flags
	Salopian Series	Lower Ludlow Beds
		Wenlock Limestone
		Wenlock Shale
		Woolhope Beds
	Valentian Series	Tarannon Shales
		Llandovery Beds
ORDOVICIAN	Bala or Caradoc Series	
	Llandeilo Series	
	Arenig Series	
CAMBRIAN.........	Upper...	Tremadoc Slates
		Lingula Flags
	Middle..	Menevian Beds
		Solva Beds (upper part of Harlech Beds)
	Lower...	*Olenellus* Beds

INTRODUCTION.

From the earliest times it has been known that bodies resembling marine animals occur embedded in the rocks. For several centuries two distinct views were held respecting their nature. By some persons they were thought to have once formed parts of living animals, and consequently to indicate that the spot where they are now found was in past ages covered by the sea. Others, feeling it difficult to account for so much geographical change as would be necessitated by this view, considered that they were not of organic origin at all, but had been formed by some 'plastic force' within the earth—that they were in fact 'Sports of Nature.' But since these bodies resemble in every essential respect the hard parts of animals now existing, we may at once reject this hypothesis.

The remains of animals and plants of past ages preserved in the rocks are known as fossils, and the study of them forms the subject of Palæontology.

In order that an animal or plant may become a fossil two conditions are generally necessary: First, it must possess a skeleton of some kind or other, since the soft parts are rapidly decomposed; consequently such animals as jelly-fishes leave no trace of their existence, unless it be a mere imprint. Secondly, the organism must be covered up by some deposit, otherwise it will soon crumble to dust. Now, since there are comparatively few places on land where material is being deposited to any great extent, it follows that terrestrial animals will stand but little chance of being preserved; the greater number after death will remain on the surface and will in a short time be entirely decomposed. A few may become entombed in peat-bogs, in the dust and ashes thrown out by volcanoes, in the sand of sand-dunes, or by a land-slip; some may be sealed up in deposits of carbonate of lime, such as the travertine thrown down by calcareous springs, or the stalagmite formed on the floor of caves; and lastly, others may be transported by running water and ultimately buried in the bed of a river, of a lake, or of the sea. Such instances, however, are of comparatively rare occurrence. In the case of aquatic animals the conditions for fossilisation are much more favourable, since deposition is more universal in water than on land. Of such aqueous deposits, those formed in the sea will enclose by far the larger number of animals on account of the greater area which these deposits cover.

The structure and composition of the hard parts vary considerably in different groups of animals and plants; some are therefore much more readily preserved as fossils than others. Thus in *Argonauta* the skeleton consists of a thin shell which is easily broken up; then again in some sponges it is formed of needles of silica, which are held together by the soft parts only and consequently easily become scattered after the death of the animal. But in other cases, as in most of the mollusks and corals, the skeleton is very strong and not easily destroyed, hence these occur abundantly in the fossil form. Perhaps even more important than the structure, is the composition of the hard parts, which, in the case of insects and some hydroids consist of a horny substance known as chitin; in diatoms, in most radiolarians, and in many sponges, of silica; in the bones of vertebrates, chiefly of phosphate of lime; in corals, echinoderms, mollusks and many other animals and some plants, of carbonate of lime; in most plants, of woody or corky tissue: a larger or smaller amount of organic matter is always combined with the mineral. Of these substances, chitin is with difficulty dissolved. Silica in its ordinary crystalline condition is one of the most stable of minerals, but when secreted by an animal or plant it is glassy and isotropic (*i.e.* singly refracting and without effect on polarised light), and is dissolved with comparative ease, so that such skeletons may be entirely removed by the action of percolating water. In organisms with calcareous skeletons the carbonate of lime is readily dissolved by water containing carbonic acid, but the degree of solubility varies according to the condition in which the carbonate of lime is present. In some animals it occurs as aragonite, in others as calcite. Of these two minerals, aragonite is the harder and heavier, its specific gravity being 2·93, whilst that of calcite is only 2·72; aragonite crystallises in the rhombic system, calcite in the hexagonal. Fossil calcite shells (*e.g. Pecten opercularis*) are translucent, their surface is compact, but their interior porous; on the other hand the aragonite shells (*e.g. Pectunculus glycimeris*) are opaque, and have a chalky appearance but a compact structure throughout. If a shell of each kind be suspended in water containing carbonic acid, it will be found that the one composed of aragonite will lose, in the same time, a much greater proportion of its weight than the other. Further, the calcite shell remains firm longer than the aragonite, the latter being soon reduced to the consistency of kaolin or china-clay. This difference, however, does not appear to be due directly to mineral composition, for Cornish and Kendall found that when crystals of calcite and aragonite were powdered and placed in carbonic acid solutions of the same strength, the aragonite was *not* acted on more rapidly than the calcite, and the same result was obtained with powdered fossil shells. From all these considerations, it is not surprising to find that in some strata the aragonite skeletons have entirely disappeared, whereas those formed of calcite remain. This will obviously be most likely to occur in pervious beds through which water containing carbonic acid percolates. A striking instance of the difference in the solubility of calcite and aragonite was furnished by some specimens of the common edible mussel, *Mytilus edulis*, in which the inner layer of the shell is formed of aragonite and the outer of calcite; Dr Sorby found specimens from the raised beach at Hope's Nose, Torquay, which had lost the inner layer but not the outer. Similarly, in specimens of *Spondylus* from the Chalk, the inner layer of the shell has been completely removed, but the outer is left. In some cases aragonite is replaced by calcite, but then the organic structure is entirely destroyed, and we get merely a mass of calcite crystals. Calcite is never replaced by aragonite.

The mineral character of the skeleton of the chief calcareous organisms is as follows:—

Foraminifera.—The vitreous forms consist of calcite, the porcellanous probably of aragonite.

Porifera.—Calcispongiæ of calcite.

Anthozoa.—The Alcyonaria are of calcite, except *He-*

liopora, which is of aragonite; the Madreporaria of aragonite.

Echinoderma.—All of calcite.

Polyzoa.—Chiefly calcite.

Brachiopoda.—All of calcite.

Lamellibranchia.—Many consist entirely of aragonite, but *Anomia, Ostrea,* and *Pecten* of calcite. In *Pinna, Mytilus, Spondylus, Unio,* and *Trigonia,* the inner layer is of aragonite, the outer of calcite.

Gasteropoda.—The majority are formed of aragonite, but *Scalaria* and some species of *Fusus* are of calcite. In some (*e.g. Patella, Littorina*) the outer layer is calcite.

Cephalopoda.—*Nautilus, Spirula,* and *Sepia* are mainly aragonite, as also were probably the Ammonites. *Argonauta* and the guard of *Belemnites* are calcite.

Crustacea.—The shell consists of calcite, with some phosphate of lime. In some cases there is a large amount of organic matter.

The condition in which fossils occur depends, as we have seen, on their original composition and on the material in which they are embedded. The chief types are the following:—

1. *The entire organism preserved.* Occasionally the soft parts of the organism are preserved as well as the skeleton, the whole having suffered very little change. Instances of this are, (*a*) the woolly rhinoceros and mammoth found frozen in the mud and ice in Northern Siberia, and (*b*) insects and plants encased in fossil resin, known as amber, found in the Oligocene beds on the Baltic shores of Prussia and in the Pliocene beds of Cromer.

2. *The skeleton preserved almost unchanged.* Sometimes when the skeleton alone is preserved, it remains almost in its original condition, except that it has lost its organic matter. Thus the shells in the Pliocene beds of England differ from living ones only in being lighter, more porous and generally colourless. In some instances a certain amount of mineral matter, such as carbonate of lime, has been added to the skeleton, making it heavier and more compact.

3. *Carbonisation.* In some plants, and in animals with chitinous skeletons, such as graptolites, the original material becomes carbonised. The organism undergoes decomposition and loses oxygen and nitrogen, the relative percentage of carbon therefore increasing. The changes are similar to those which occurred during the conversion of vegetable matter into coal.

4. *A mould of the skeleton.* Sometimes the skeleton disappears entirely, a mould only remaining: this is especially the case when it consists of aragonite and is embedded in a porous stratum. After the shell of a mollusk has become covered up with sediment, and the soft parts have been decomposed, the interior becomes filled with the same material. Water containing carbonic acid subsequently percolates through the rock and carries away the shell as bicarbonate of lime, so that there is left only a mould of the interior and of the exterior, the space between the two being that which was originally occupied by the shell and, if filled with wax, will give an exact model of it. Excellent examples of this mode of fossilisation are seen in some mollusks from the Portland Oolite, *e.g. Cerithium* and *Trigonia.* Sometimes after the shell has been removed the space left becomes filled up

with mineral matter carried in by percolating water; this has the form of the original skeleton but obviously not its internal structure.

The interior of the shells of foraminifera or other organisms may, soon after the death of the animal, become filled with glauconite (silicate of iron and alumina), calcite, or silica; subsequently the shell itself often disappears, leaving only the internal cast. Glauconite occurs in this way in the various greensand strata, and also in some of the deep-sea deposits at the present day.

5. *Petrifaction.* In some deposits the fossils show the minute structure as well as the form of the organism, but the original material of the skeleton has been replaced by another mineral. Thus we find fossil wood which shows the cells and vessels just as in existing trees, but in which the walls are formed of silica instead of cellulose. The change has gone on in such a manner that as each particle disappeared its place was taken by a particle of silica. The chief minerals which replace the original substance of organisms in this manner are:—

(i) Carbonate of lime; calcite sometimes replaces the silica of sponges.

(ii) Silica, as in the fossils from the Blackdown Greensand, and the Thanet Sands near Faversham; also in the wood of the Purbeck dirt-bed in the Isle of Portland.

(iii) Iron pyrites; *e.g.* Ammonites from the Oxford Clay, Lias, etc., and some graptolites.

(iv) Oxide of iron, in the form of limonite in some fossils from the Dogger (Inferior Oolite) of Yorkshire and the Lower Greensand of Potton, etc., and as hæmatite in fossils from the Carboniferous Limestone of Cumberland.

(v) In rare cases there are other replacing minerals, such as sulphate of lime, barytes, blende, galena, malachite, vivianite, and spathic iron.

6. *Imprints.* The footprints of animals and the impressions of jelly-fishes are sometimes found in the rocks, and these, although forming no part of the animal itself, are nevertheless regarded as fossils.

In endeavouring to discover the changes which have taken place on the earth in past geological times, the evidence furnished by fossils is of primary importance. Each great group of the stratified rocks, known as a system, is characterised by a particular assemblage of genera and species, some of which are confined to it and enable us to identify the system. In a similar manner, the smaller divisions—the series and stages, are each characterised by possessing certain fossils, which do not occur above or below. Further, it is found that the fauna of the smallest division (stage or group of beds) is not of uniform character throughout; although there may be no change in the nature of the rock, some of the species which are abundant at one level will become rare or will disappear entirely in passing to higher or lower horizons. Consequently, a set of beds may be divided into belts or zones, the general aspect of the fauna of each zone being somewhat different from that of the others, but between these divisions there will be no break either physical or palæontological. If then we have determined the order of succession of the formations in any one area by means of their relative positions, the newer resting on the older, it is fairly easy in any other district, merely by examining the fossils, to refer any set of beds to its proper position in the geological record. But although this law of the identification of strata by the fossils which they contain is of great value, it must not be applied without some caution, for even if two formations were deposited at exactly the same time, it does not necessarily follow that all the genera and species found in the two will be identical. Thus for instance in the seas at the present day the same forms of life do not occur in all parts; animals which live in water of moderate depth are distributed in provinces which depend largely on climatic conditions, each province possessing some forms peculiar to itself. The organisms now being entombed in deposits formed, say, off the British coasts, will as a whole be different from those off the Canary Islands; but still, some of the species and many of the genera will be common to both areas, and would enable us to identify the two deposits as having been formed within the same general period, though not to consider them absolutely synchronous. Then again there is a distribution of organisms according to the depth of the sea, and the nature of the sea-bottom; so that the fauna of a deep-water formation will necessarily be different from that of a shallow-water one, and that of a sandstone different from that of a clay. But there are other animals which live near the surface of the ocean, far from land; such *pelagic* forms have a wider geographical range than those which live on the sea-floor in shallow-water, and are consequently of great value in determining, as of the same age, deposits found in widely-separated localities.

In addition to their chronological value, fossils are also important in indicating the conditions under which the formations were deposited. In the case of the later beds, where most of the fossils belong to genera which are still existing, it is easy to distinguish a marine deposit from one formed in freshwater or on land. Even in the rocks of earlier periods, in which most of the genera are extinct, we may recognise a marine deposit by the presence of such animals as radiolarians, corals, echinoderms, brachiopods, pteropods, cephalopods, or cirripeds, which at the present day are found only in the sea.

The depth of the sea in which a formation was deposited can be estimated when the fossils belong to living species; when the species are extinct some idea may be formed if the genera to which they belong are found chiefly at some particular depth at the present day. In attempting such determinations it must be remembered that the sea-bottom down to a depth of nearly 50 fathoms may be disturbed by the action of waves and currents in the sea; consequently the animals living on the bottom in shallow water are liable to be carried from their original home to higher or lower levels. One of the surest indications that a formation was laid down in shallow water and not far from land is furnished by the association of the fossil remains of land animals and plants with marine species; another, by the presence of mollusks such as *Pholas* and *Lithodomus*, which bore into rocks, and at the present day are found only in shallow water.

The nature of the climates of past ages may be judged to some extent by the character of the fossils; the evidence furnished by land-plants is particularly valuable, since their distribution is determined largely by temperature and is better marked than in the case of marine animals. As far as the latter are concerned it is only when we are dealing with modern species that we can, as a rule, speak with any degree of certainty on this subject; this is owing to the fact that at the present day the individual species of the same genus have often a very different distribution, some being found in warm, others in cold, regions. Even when all the fossils in a formation belong to extinct species, the assemblage of genera is sometimes such as marks some region at the present day; thus, for example, in the London Clay we find that many of the genera of mollusks are now characteristic of tropical or subtropical seas.

The study of fossil animals and plants is of the highest importance to the biologist, not only because they are the ancestors of modern species, but because among fossil forms we find many groups (*e.g.* Graptolites, Cystids, Blastoids, Trilobites, Eurypterids), which are altogether extinct, and which often throw light on the relationship of existing animals and plants. Others (*e.g.* Crinoids, Brachiopods, Nautiloids) are represented at the present day by few forms only, but were, in past ages, very abundant; consequently no adequate knowledge of such groups of animals can be obtained from the study of living examples only. In some cases the ancient forms serve to connect groups which, at the present day, appear to be quite distinct; thus, for example, the earliest known bird (*Archæopteryx,* from the Solenhofen Limestone, Upper Jurassic) shows, in several important characters, affinities to the Reptiles; on the other hand the Deinosaurs, a group of reptiles found in the Mesozoic formations, have many features which link them with the Birds. From the point of view of the biologist, the greatest interest in Palæontology is found in the bearing it has on the subject of evolution: it is only by a study of the fossil forms that the race-history or phylogeny of animals and plants can be traced with certainty; but in attempting such investigations a great difficulty is presented by the imperfection of the record of the life of past ages, since only a very small proportion of the animals and plants has been preserved, and these often in a very imperfect manner. We have already seen several reasons why this record must be imperfect; some animals are without hard parts, while others, particularly land animals, do not become covered up with sediment. Further, the remains of animals which were originally present in some rocks have been dissolved by percolating water, or to a great extent obliterated by the metamorphism which the rock has undergone. Then again the record of life is incomplete because of the breaks in the succession of the stratified rocks; these breaks have been caused sometimes by denudation having removed a great thickness of rocks, in other cases by an absence of deposition.

Notwithstanding this imperfection of the record, many groups of animals are found to undergo gradual modification when traced through series of strata or formations. For example, in the Pliocene deposits of Slavonia there are numerous shells of pond-snails (*Viviparus* or *Paludina*); and specimens found at the top and bottom of the formation, and also at certain intervening levels, differ so much from one another that they appear to belong to distinct species. When, however, examples are collected from all the beds of the formation, the apparently distinct species are seen to be connected by intermediate forms, and a series, showing a gradual passage from the species found in the lowest bed to that in the highest, can be obtained.

In several groups of Tertiary Mammalia there is also evidence of gradual modification in structure; thus the earliest-known forerunner of the horse, found in the Eocene beds, possessed five toes, and was succeeded in later times by forms with successively fewer toes, until in the Pliocene, the existing type (*Equus*), with only one toe and splint-bones, appeared; other gradual changes also occurred in the character of the teeth, etc.

In the development and growth of an animal, various stages, which often present some resemblance to the adults of other animals, are passed through. In some cases these stages in the life of the individual are also similar to those which occurred in the history of its race, as shown by the geological record. This agreement gives some support to the 'recapitulation theory,' which supposes that the changes passed through in the development of the individual (ontogeny) are, in a general way, a rapid and incomplete repetition of those which occurred in its race-history (phylogeny).

In a natural classification of animals an attempt is made to place together in the same group those forms which are connected by descent; such a classification, if perfect, would be of the nature of a genealogical tree. Each main division is termed a Phylum, and is divided and subdivided into smaller and smaller groups, known as Classes, Orders, Families, Genera, and Species. A species includes a group of individuals which appear to have descended from the same ancestors and can give rise to offspring which are fertile among themselves; such individuals usually differ from one another to only about the same degree that offspring of the same parents may differ. One species is generally distinguished from another by such characters as ornamentation, shape, relative proportion of parts, and size. In some species one or more groups termed *varieties* may be recognised, and are distinguished from the other forms included in the species by some slight, but fairly well-marked and constant modification. Varieties are frequently connected with the special physical or biological conditions under which they are living. The varieties in some species pass into one another by intermediate forms; but others appear to be fairly distinct and may be regarded as incipient species.

Sometimes two groups of individuals resemble each other so closely that they might be regarded as belonging to the same genus or to the same species, but they appear to have descended from different ancestors since they are found to differ in development (ontogeny) or in their palæontological history; this phenomenon, of forms belonging to different stocks, approaching one another in character, is known as *convergence* or *heterogenetic homœomorphy*, and may occur either at the same geological period or at widely separated intervals.

Similarly, animals belonging to two distinct groups may, when subjected to similar conditions, show corresponding modifications, though they do not really approach one another in essential characters; thus *parallel modification* may occur in independent groups.

PHYLUM PROTOZOA.

Classes.	*Orders.*
1. Gymnomyxa (Sarcodina)	1. Foraminifera. 2. Radiolaria. 3. Others not found fossil.
2. Corticata (not fossil).	

THE Protozoa include the lowest forms of animals, such as *Amœba, Vorticella,* and *Globigerina.* The body consists in many cases of one cell only, in others of more than one, but the cells never form tissues as they do in all other animals. A cell consists of *protoplasm*—a semi-fluid living substance containing granules; in the centre of the cell is a denser, usually spherical body called the *nucleus*—rarely more than one is present.

In some Protozoa (the *Gymnomyxa*) the protoplasm is naked, and consists of an inner granular mass and a thin, clear, outer layer; such forms are further characterised by having no definite shape, by being able to take in food at any part of the body, and by possessing the power of throwing out lobes or filaments of protoplasm known as *pseudopodia.* In others (the *Corticata*) the protoplasm is surrounded by a firm membrane or cuticle which gives the animal a definite form; the food is generally taken in at one permanent aperture, and pseudopodia are absent, but in many cases the surface is provided with *cilia* or *flagella,* which are threads of protoplasm having a definite form and a rhythmic movement.

Reproduction in the Protozoa takes place usually by fission (*i.e.* division into two parts) and sometimes by the formation of spores. There are some cases in which conjugation occurs, representing to some extent the sexual method of the higher animals. In some of the Protozoa there is no skeleton, but in others a shell is formed.

The Protozoa can be divided into two main groups, (1) the Gymnomyxa, (2) the Corticata; no examples of the latter division have been definitely recognised in the fossil state.

CLASS I. GYMNOMYXA.

The members of this group possess no external membranes (cuticle), and are able to throw out pseudopodia.

The Gymnomyxa are divided into five or more orders, but only two of these have been found fossil, namely, the Foraminifera (or Reticularia) and the Radiolaria.

ORDER I. FORAMINIFERA.

The Foraminifera are characterised by giving out thread-like pseudopodia, which frequently branch and anastomose; and by possessing in most cases a shell or test, which may be calcareous, arenaceous, or chitinous.

The calcareous forms are by far the commonest, and in these, two kinds of shell may be distinguished, namely, the *vitreous* and the *porcellanous*. In the vitreous, the shell is glassy and transparent, and is perforated by innumerable tubes for the passage of the pseudopodia; in some forms (*e.g.* *Rotalia*) these tubes are $\frac{1}{3000}$ of an inch in diameter, but in others (*e.g.* *Operculina*) only $\frac{1}{10000}$ of an inch. In the porcellanous forms, the shell, when viewed by reflected light, is opaque and white, having the appearance of porcelain; it is not perforated by tubes, the whole of the pseudopodia passing out by one or two large apertures. Sometimes, however, the surface of the shell is pitted, producing at first sight the appearance of perforation.

In the arenaceous forms the shell consists of grains of sand (commonly quartz) joined together by a cement. The cement may be formed of chitinous, or of calcareous and ferruginous material. The shell is often imperforate.

The chitinous forms (*e.g. Gromia*) do not occur as fossils.

The shell of the Foraminifera varies considerably in form; in some genera it consists of a single chamber, when it is said to be *unilocular*, as for example in *Orbulina*, where it is spherical, and in *Lagena* (fig. 2, *F*), where it is generally flask-shaped. In other cases it consists of several chambers, which are placed in communication with one another, either by perforations in the walls (septa) between them, or by larger openings. The arrangement of the chambers in these *multilocular* forms is very varied; they may be placed in a straight line as in *Nodosaria* (fig. 2, *H*), in a curved line as in *Dentalina*, in a plane spiral as in *Cristellaria* (fig. 2, *G*), or in a helicoid spiral as in *Rotalia* (fig. 2, *L, M*). The earlier whorls in some spiral forms are partly or entirely embraced by the later ones, so that sometimes the last whorl only is visible on the exterior (*e.g. Cristellaria*); but when the later chambers are merely attached to the extremities of the earlier ones, all the whorls can be seen (*e.g. Operculina*). Some genera, such as *Textularia* (fig. 2, *E*), have two rows of chambers placed side by side; others (*Tritaxia*) have three. In some cases (*e.g. Orbitolites*) there are numerous chambers arranged in concentric rings instead of in a spiral.

In the porcellanous and the simpler vitreous forms the septum between the chambers (fig. 1, *A*, *b*) is formed entirely by the wall of the older chamber, but in the higher vitreous forms each chamber possesses a wall of its own, so that the septum (fig. 1, *B*, *b*) is formed of two lamellæ. In such cases the outer walls of the chambers are frequently strengthened by an external deposit, which fills up the hollows between them: this deposit is often traversed by a system of canals, and is known as the *supplemental* or *intermediate skeleton* (fig. 1, *B*, *d*).

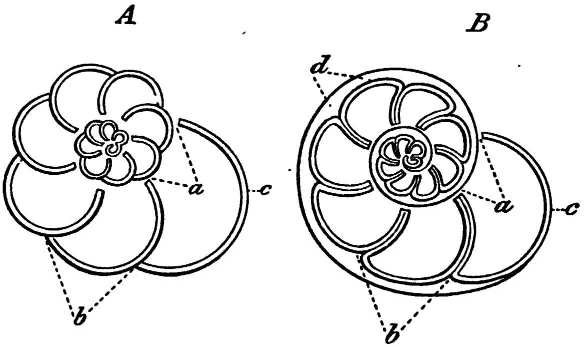

FIG. 1. *A*, section of a foraminifer in which each septum is formed of a single lamella. *B*, in which the septum is formed of two lamellæ. *a*, passages between the chambers; *b*, septum; *c*, anterior wall of last chamber; *d*, supplemental skeleton. (After Carpenter.)

The Foraminifera may be divided into three groups, the characters of which are based on the structure and composition of the shell; this is most probably not a natural classification since in some types which are usually calcareous (*e.g. Miliola*) we occasionally meet with species having sandy shells.

I. *Porcellanous Forms.*

Shell calcareous, porcellanous, not perforated by canals, but provided with one or two large apertures through which all the pseudopodia pass out.

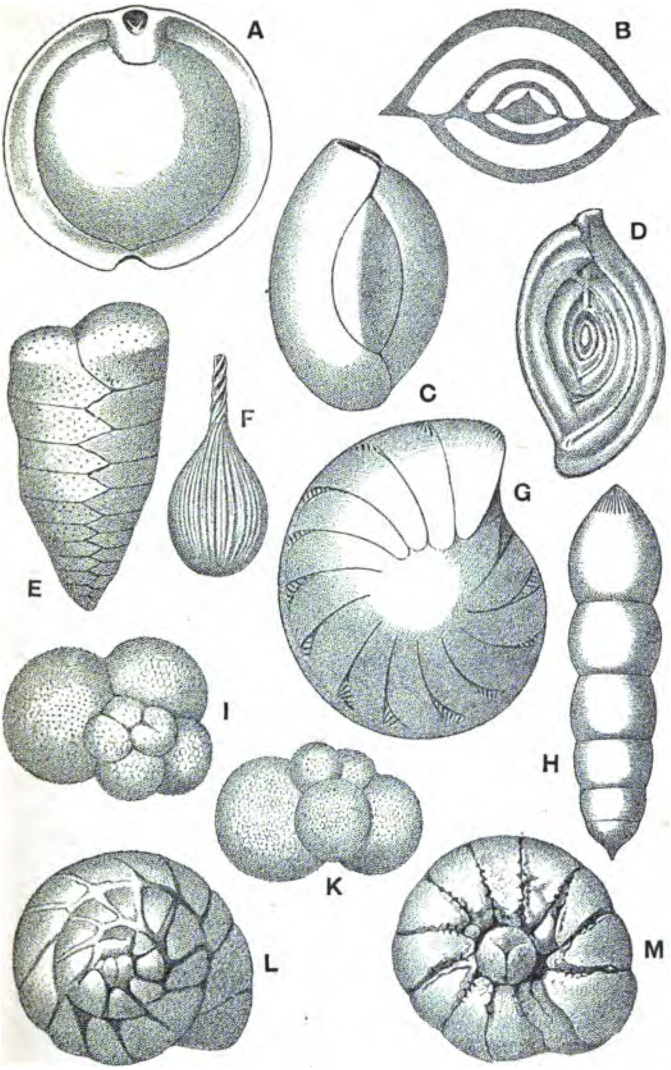

FIG. 2. Foraminifera (recent). *A*, *B*, *Miliola* (*Biloculina*) *depressa*. *B*, section. *C*, *Miliola* (*Miliolina*) *seminulum*. *D*, *Miliola* (*Spiroloculina*) *limbata*. *E*, *Textularia barretti*. *F*, *Lagena sulcata*. *G*, *Cristellaria rotulata*. *H*, *Nodosaria radicula*. *I*, *K*, *Globigerina bulloides*. *L*, *M*, *Rotalia beccari*. (After Brady.) All enlarged.

Miliola. (fig. 2, *A—D.*) Shell multilocular, the chambers being coiled on an elongated axis, each chamber forming half a convolution. Sometimes all the chambers are visible externally on both sides of the shell (fig. 2, *D*); at other times, owing to the lateral prolongations of the chambers, only the last one or two are seen (fig. 2, *A*, *C*); or it may be that more chambers are shown on one side than on the other. The external features of the shell consequently vary considerably, and on this account the forms included under the term *Miliola* are now regarded as constituting a number of distinct genera to which the following names have been given:—*Biloculina*, *Fabularia*, *Spiroloculina*, *Miliolina*, *Quinqueloculina*, etc. Trias to present day. Ex. *Miliolina seminulum*, Eocene to present day; *Biloculina ringens*, Eocene to present day; *Spiroloculina planulata*, London Clay to present day.

Orbitolites. Shell discoidal, generally rather large, composed of either a small spiral part at the centre, or of one or more large central chambers, around which are many concentric rings divided into numerous chambers; the chambers of adjacent rings communicate by radial openings, and at the external margin of the last ring are pores opening to the exterior. Above and below this layer of chambers there may be another layer of smaller chambers, arranged concentrically. Upper Cretaceous to present day. Ex. *O. complanata*, Eocene.

Alveolina. Shell fusiform or elliptical, sometimes nearly globular, composed of many whorls coiled around the long axis of the shell; each whorl completely covers the one preceding it, and is divided into long chambers by partitions parallel with the axis of the shell; these are divided into smaller chambers by partitions at right angles to the others. Chalk to present day; chiefly Eocene. Ex. *A. bosci*, Eocene.

II. *Arenaceous Forms.*

Shell composed of grains of sand cemented together by chitinous, calcareous, or ferruginous material.

Saccamina. Shell usually free, compact, formed of a single spherical, pyriform, or fusiform chamber with a projecting aperture, or of a number of chambers united end to end. Surface smooth or nearly smooth. Ordovician, Carboniferous, and living. Ex. *S. fusuliniformis* (=*carteri*), Carboniferous Limestone.

Lituola. Shell free, composed of coarse grains, spiral or crosier-shaped. Septa labyrinthine. Aperture simple or sieve-like. Carboniferous to present day. Ex. *L. nautiloidea*, Chalk.

Orbitolina. Shell partly sandy, conical or flattened, with convex upper, and usually concave lower surface; consisting of central compressed chambers surrounded by concentric rings of chambers. Cretaceous. Ex. *O. concava*, Upper Greensand.

Endothyra. Shell free, spiral (similar to *Rotalia*); chambers numerous, composed of an outer calcareous, perforated layer, and an inner compact layer formed of small grains cemented together. Aperture at the inner margin of the last chamber. Carboniferous to Trias. Ex. *E. bowmani*, Carboniferous Limestone.

Textularia. (fig. 2, *E.*) Shell arenaceous (in the small forms it is vitreous); form variable, conical, pyriform, or cuneiform; composed of numerous chambers in two alternating parallel series. Aperture slit-like on the inner edge of the last chamber. Cambrian to present day. Ex. *T. globulosa*, Chalk.

III. *Vitreous Forms.*

Shell calcareous, vitreous, perforated by numerous minute canals for the passage of the pseudopodia.

Lagena. (fig. 2, *F.*) Shell unilocular, very finely perforated. Form globose, ovate or flask-shaped. A single terminal aperture, sometimes at the end of a long neck; rarely two apertures. Surface smooth, ribbed, striated, or spinous. Cambrian to present day. Ex. *L. striata*, London Clay to present day, *L. sulcata*, Silurian to present day.

Nodosaria. (fig. 2, *H.*) Shell composed of a number of chambers arranged in a straight line, and separated by constrictions. Aperture at the apex of the last chamber. Surface smooth or ornamented with granules, spines, or ribs. Cambrian to present day. Ex. *N. zippei*, Gault and Chalk.

Cristellaria. (fig. 2, *G.*) Shell compressed, lenticular or elongate, multilocular, coiled in a plane spiral; each coil usually covers the one preceding it. Cambrian to present day. Ex. *C. rotulata*, Chalk.

Globigerina. (fig. 2, *I*, *K.*) Shell perforated by large canals; chambers globular, few, arranged in a plain or helicoid spiral, each chamber opening by a large aperture into a central cavity. No supplemental skeleton. Cambrian to present day. Ex. *G. cretacea*, Chalk.

Orbulina. Shell spherical, with perforations of two sizes. Sometimes with smaller chambers inside the large spherical one. Lias to present day. Ex. *O. universa*, Lias to present day.

Rotalia. (fig. 2, *L*, *M.*) Test very finely perforated, multilocular. The chambers arranged in a helicoid spiral, so that on the upper surface all the whorls are seen, on the lower only the last one. The aperture is in the form of a curved slit on the lower surface of the last segment. The septa are usually formed of two layers. A supplemental skeleton is often present. Lower Cretaceous to present day. Ex. *R. beccari*, Miocene to present day.

Calcarina. Test lenticular, spiral, with only the last whorl visible on the base. Supplemental skeleton greatly developed, traversed by numerous canals, and projecting as long spines from the margin. Chalk to present day. Ex. *C. calcitrapoides*, Chalk.

Fusulina. Shell fusiform, composed of elongated whorls; each whorl completely covers the preceding one, and is divided by septa into a number of chambers, which may be again divided into smaller chambers. Adjoining chambers communicate by a slit at the middle of the base of the septum. Septa folded, each consisting of a single layer. Aperture in the form of a fissure. Carboniferous and Permian. Ex. *F. cylindrica*, Carboniferous Limestone.

Amphistegina. Shell lenticular, with sharp edge; the upper and lower surfaces unequally convex; formed of numerous chambers coiled in a plane spiral, each coil almost completely enclosing the preceding one. Septa formed of a single layer. Supplemental skeleton at the centre of the shell. Aperture similar to that of *Rotalia*. Carboniferous, and Miocene to present day. Ex. *A. haueri*, Miocene.

Nummulites. (fig. 3.) Shell lenticular in form, and composed of a large number of whorls coiled in a plane spiral. Usually each whorl completely covers the preceding one by means of the lateral prolongations of the chambers, so that externally only the last whorl of the shell is visible. The whorls are divided into chambers (*c*) by septa (*b*) which are slightly curved backwards; each chamber communicates with the neighbouring one by means of a median fissure at the inner margin of the septum. Each septum is formed by two lamellæ. A supplemental skeleton is present, part of it forming what has been termed the 'marginal cord' (*a*). The general shell-substance is minutely perforated, and a system of canals also traverses the septa and supplemental skeleton. Aperture in the form of a slit at the inner margin of the last chamber. The earliest species of *Nummulites* occurs in the Carboniferous Limestone of Belgium; others have been recorded from the Upper Jurassic of Amberg (Bavaria); the genus attains its maximum in the Eocene; only one or two rather rare forms are living, one of which (*N. cummingi*) is found in shallow water in tropical and sub-tropical regions. In the English Eocene the genus is found in the Barton and the Bracklesham Beds. Ex. *N. lævigatus*, Bracklesham Beds.

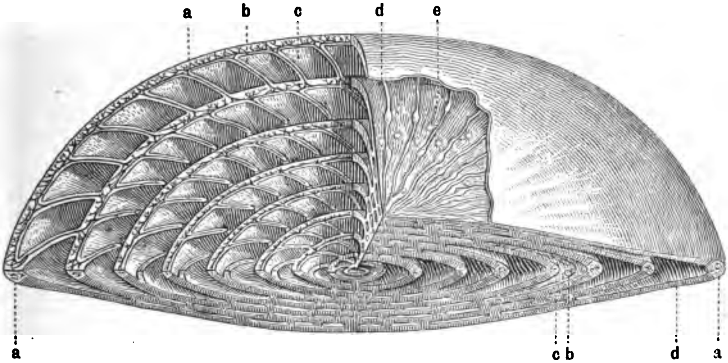

FIG. 3. *Nummulites*, showing vertical and horizontal sections. *a*, marginal cord, with system of canals; *b*, septum, with canals; *c*, chambers; *d*, test; *e*, pillars coming from the supplemental skeleton. (After Zittel.) Enlarged.

Operculina. Similar to *Nummulites*, but whorls fewer and rapidly enlarging; each whorl not completely enclosing the preceding one. Cretaceous to present day. Ex. *O. complanata*, Miocene.

Orbitoides. Test lenticular or discoidal, composed of a median layer of rectangular chambers arranged in concentric rings which are often incomplete; the chambers of adjacent rings communicate by oblique passages. Above and below this layer are numerous layers of smaller chambers; these chambers are flattened and irregular in form, placed one above the other in piles, and arranged more or less concentrically. The test is minutely perforated, and canals traverse the septa and marginal cord as in *Nummulites*; the septa are also formed of two lamellæ. Chalk to Miocene; chiefly Eocene. Ex. *O. papyracea*, Eocene.

Distribution of the Foraminifera.

The majority of the Foraminifera are marine, most of them living on the sea-bottom. A few however, as for instance *Globigerina*, exist at or near the surface in the open ocean, and these are very important on account of their abundance. The distribution of the Foraminifera which live in the open ocean, as well as those found in shallow water, is influenced largely by temperature; the former are more numerous in the courses of the warm ocean-currents than in colder water, whilst the species of the latter often have their range restricted by temperature.

Foraminifera are found in the Cambrian rocks, but they are comparatively rare until we reach the Carboniferous, some beds of which are formed largely of them, as for instance, the *Saccamina*-limestone of the north of England and Scotland, the *Endothyra*-limestone of North America, and the *Fusulina*-limestone of Russia, America etc. The Foraminifera are mostly of small size in the Permian of England; they are comparatively rare in the

Trias, but become abundant in the Jurassic, where, however, rock-building types are generally absent. In the Lias the introduction of numerous vitreous forms (*Nodosaria, Cristellaria* etc.), many of which appear to be allied to species now living in tropical or warm-temperate regions only, is noteworthy; some porcellanous forms belonging to the *Miliola* group are also fairly common. A larger number of genera and species are found in the Middle and Upper Jurassic than in the Lias.

The Order continues to be well represented in the Cretaceous formations, particularly in the Gault and Chalk—*Orbitolina, Calcarina, Globigerina, Rotalia* etc. being common. Some of the beds of the Chalk, especially the *Micraster* zones and the Chalk Rock, are largely composed of Foraminifera such as *Globigerina, Textularia, Bolivina, Flabellina.*

The Foraminifera attain their greatest development in Tertiary and recent times. In the Eocene the genus *Nummulites* is extremely abundant, forming the massive Nummulitic Limestone of Southern Europe, Egypt, Asia Minor, and the Himalayas; *Miliola, Orbitolites, Alveolina, Operculina,* and *Orbitoides* are also important rock-building forms in the Eocene period. In the English Eocene, Foraminifera are numerous in the Thanet Sands and the London Clay; in the Barton and Bracklesham Beds *Nummulites, Miliolina, Alveolina* etc. occur. *Amphistegina* is abundant in the Miocene. A large number of forms occur in the Pliocene deposits of East Anglia and of St Erth in Cornwall.

The genera and species of the Foraminifera have generally, as might be expected from their low organisation, a long range in time; some of the species which occur in the Palæozoic are still living.

ORDER II. RADIOLARIA.

In the Radiolaria the body consists of a central mass of protoplasm, enclosed in a membrane known as the *central capsule* (fig. 4, 2). The intracapsular protoplasm contains one or more nuclei, and is continuous, through pores in the capsule, with a layer of protoplasm outside the capsule; this layer gives off thread-like pseudopodia, which occasionally unite. A skeleton (fig. 4, 1) is generally developed, composed either of silica, or a peculiar horny substance known as acanthin. The form of the skeleton varies considerably (fig. 5): it may be entirely outside the central capsule or partly within, and consists either of isolated spicules, or of a lattice-like structure of varying shape, frequently with projecting spines.

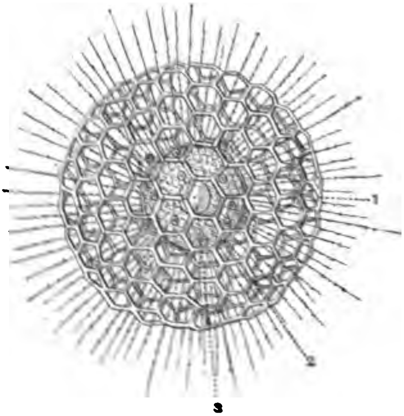

FIG. 4. *Heliosphaera inermis.* × 350. Recent. (After Bütschli.) 1, skeleton; 2, central capsule; 3, nucleus. Pseudopodia project from the edge.

The Radiolaria do not live in fresh water, but they have a very wide distribution in the sea, where they are found in all climates and at all depths, showing the greatest variety of form in tropical regions. In some of the deeper parts of the Pacific and Indian Oceans the shells of these animals, after death, fall and accumulate on the sea-bottom, forming a siliceous deposit known as ‘Radiolarian ooze.’

Cayeux has recently described as Radiolaria some bodies found in the Pre-Cambrian rocks of Brittany; they are much smaller than later forms of the group, and are thought by some authors to be simply inorganic aggregations.

In Britain the earliest examples of the Radiolaria occur in the Ordovician rocks of the south of Scotland, where they form beds of chert; others which are perhaps of nearly the same age, have been found in a chert from Mullion Island (off the west coast of the Lizard). A few

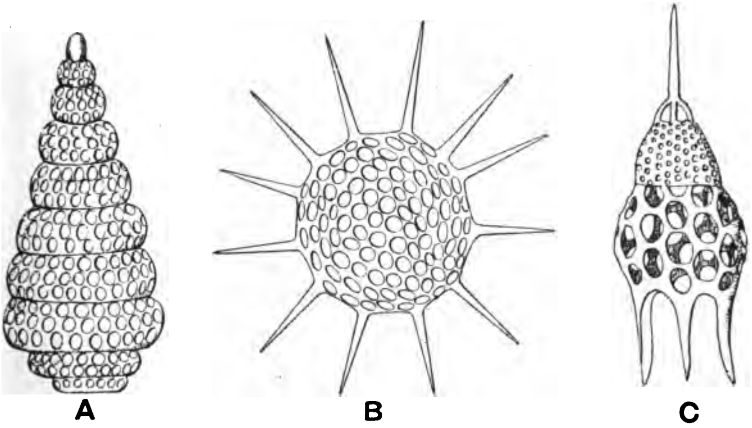

FIG. 5. Fossil Radiolaria. *A*, *Lithocampe tschernyschewi*, Devonian. *B*, *Trochodiscus longispinus*, Carboniferous. *C*, *Podocyrtis schomburgki*, Barbados Earth (Tertiary). All largely magnified.

specimens have been noticed in the Carboniferous Limestone of Flintshire, whilst in the Lower Culm of Devon and Cornwall these organisms contribute largely to the formation of thick beds of siliceous rock (cherts, etc.). At several localities on the continent Radiolaria are fairly common in the Mesozoic formations, but in England only a few have been recorded from the Lias, the Lower Greensand, the Upper Greensand, the Cambridge Greensand, and the Chalk. In the Tertiary some have been obtained from the London Clay of Sheppey. A very important Radiolarian formation of late Tertiary age covers large areas in the Island of Barbados, and is known as the 'Barbados Earth'; it resembles very closely the modern Radiolarian ooze mentioned above, and is probably a deep-sea deposit.

PHYLUM PORIFERA.

Classes.	*Orders.*
1. **Hexactinellida.**	
2. **Demospongiæ**	1. **Myxospongida.**
	2. **Ceratosa.**
	3. **Monaxonida.**
	4. **Tetractinellida.**
	5. **Lithistida.**
	6. **Octactinellida.**
	7. **Heteractinellida.**
3. **Calcarea (Calcispongiæ).**	

SPONGES vary greatly in form, size, and complexity of structure. A simple type is similar to a vase or hollow sac, fixed by the lower end, and with an opening or *osculum* at the upper extremity. The wall of such a sponge is thin, and perforated by a large number of pores through which water flows into the central or *gastral cavity* and passes out by the osculum; by this means the sponge is provided with food and oxygen and gets rid of waste matters. The wall of the sponge consists of two layers—an outer or *dermal* and an inner or *gastral*; the dermal (fig. 6, 2) is formed of a surface-layer of flattened cells, with a gelatinous layer beneath containing various cells, some of which give rise to the skeleton. The gastral layer (fig. 6, 3) consists of a single layer of cells, each cell being provided with a collar-like projection, in the centre of which is a long flagellum; the circulation of water through the sponge is produced by the movements of these flagella.

A simple form like that just described is found in the

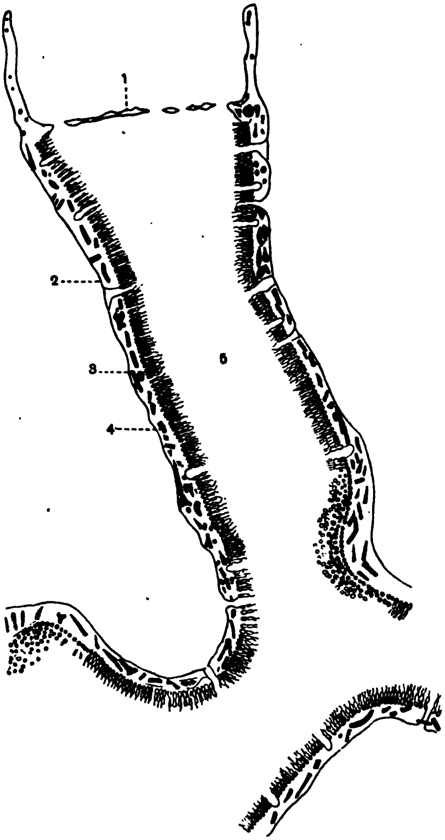

FIG. 6. Vertical section through *Leucosolenia*. Highly magnified. (From Minchin.) 1. Sieve-like membrane covering the osculum; 2. Outer layer; 3. Collar or flagellated cells (the pointer should have been continued to indicate the cells lining 5); 4. Spicules; 5. Gastral cavity.

young stages of many sponges which afterwards, in their adult condition, are much more complex. Owing to the growth of the sponge-wall being unequal in different parts, either folds or tube-like projections are formed, and these subsequently become more or less completely fused, so that the wall is much thickened (fig. 7) and is traversed by canals which are really spaces enclosed between the folds and outgrowths. In such forms the flagellated cells are frequently confined to chambers in the sponge-wall (fig. 7, 4). Canals, called *incurrent* or *inhalent* canals (2), pass from the surface of the sponge to these chambers, and others, the *excurrent* or *exhalent* canals, may lead from the

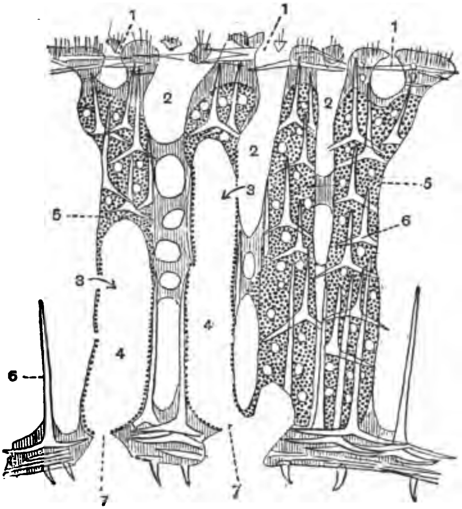

FIG. 7. Section of a portion of *Grantia*. Highly magnified. (From Dendy.) 1. Openings of inhalent canals; 2. Inhalent canal; 3. Openings of inhalent canals into flagellated chamber; 4. Flagellated chamber; 5. Collar cells; 6. Spicules; 7. Exhalent opening of flagellated chamber.

chambers and open into the gastral cavity. Further complications, such as branching of the canals, may occur. The thick wall of these more complex sponges is formed mainly of the gelatinous layer.

In a sponge consisting of a single individual, the form depends mainly on the relative rates of growth in different directions, and may be cylindrical, vase-like, globular, discoidal, etc. In a compound sponge the form depends also on the way in which the young individuals of the colony are attached to the parent, and in addition, on their remaining free or becoming fused together; in the latter case the individuals of the colony are frequently distinguishable by their oscula only. When the individuals remain free, arborescent or bushy colonies may result. If they become fused, the sponge may be fan-shaped, funnel-shaped, cup-like, tubular, mushroom-shaped, massive, encrusting, etc.

Nearly all sponges are attached to some foreign object —generally by the base of the sponge, but in forms which are fixed in the mud, especially deep-sea forms of the Hexactinellida, and in some Tetractinellida, this fixation is by means of a root-tuft or rope.

In nearly all sponges there is a skeleton, which serves to support the canals and chambers and also for protection. This skeleton may consist of fibres of a horny substance, similar to silk in composition, and known as *spongin,* or of mineral particles, termed *spicules* (fig. 8), composed of carbonate of lime or of silica; or it may consist of both siliceous spicules and spongin. Those forms only which have either a siliceous or calcareous skeleton are definitely known as fossils. Each spicule consists of a number of rays or arms, coming off from a centre, which is the point where the formation of the spicule commenced. In some groups, as for instance in the Monaxonida and Tetractinellida, the spicules are not united or are joined by spongin only; but in others they are fused together or interlocked so as to form a complete scaffolding, and generally it is in these only that the external form of the sponge has been preserved in the fossil state. In most siliceous sponges, two kinds of spicules may be distinguished, the *skeletal-spicules* or *megascleres* which build the main part of the skeleton, and the *flesh-spicules* or *microscleres* which are smaller and isolated and are seldom preserved as fossils. In the centre of each spicule there is a canal known as the *axial canal* (fig. 8, *c*), which in the living sponge is occupied by a thread of organic matter; this is the first part of the spicule to be formed, the mineral matter subsequently appearing around it.

The spicules of recent siliceous sponges are characterised by the glassy appearance of their surface, and by the silica being colloidal, isotropic, and soluble in heated caustic potash. But in the fossil state the spicules have generally undergone considerable change; occasionally their silica is still colloidal but the surface has no longer the glassy appearance, and the axial canal is frequently filled with secondary silica in a crystalline or crypto-crystalline condition, and is consequently easily distinguished by the aid of polarised light when the spicule itself still remains colloidal. Generally, however, the spicule has become crystalline or crypto-crystalline, and in such cases the axial canal can rarely be detected since it is filled with material in the same condition. Sometimes the silica of the spicules has been entirely removed, a hollow cast only remaining; in other cases it is replaced by another mineral, as for instance by calcite in the sponges from the Lower Chalk of Dover and Folkestone, by iron pyrites in *Protospongia*

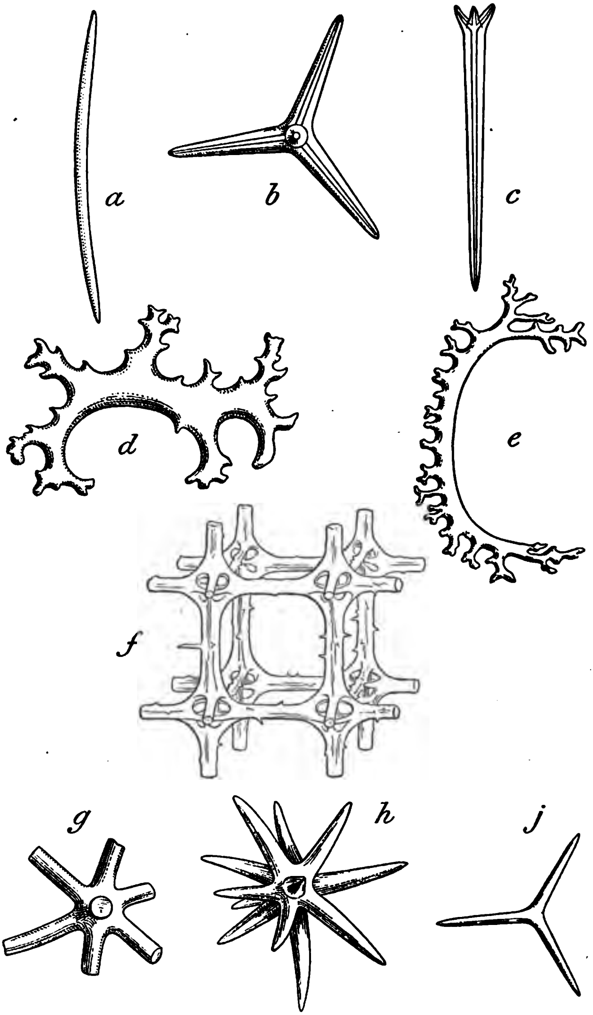

Fig. 8. Sponge spicules (skeletal). *a*, monaxonid, *Halichondria panicea*, Recent. *b*, tetractinellid, *Pachastrella*, Upper Greensand. *c*, tetractinellid, *Geodites*, Eocene. *d*, lithistid, *Scytalia radiciformis*, Chalk. *e*, lithistid, *Seliscothon mantelli*. *f*, hexactinellid, *Cœloptychium agariooides*, Chalk. *g*, octactinellid, *Astræospongia*, Silurian. *h*, heteractinellid, *Asteractinella expansa*, Carboniferous. *j*, calci-sponge, *Grantia compressa*, Recent. All magnified.

from the Menevian Beds of St David's, by iron peroxide in the sponges of the Upper Chalk of the south of England, and by glauconite in some from the Upper Greensand. Obviously then, the colloidal silica of recent sponges is anything but a stable substance, thus differing widely from crystalline and crypto-crystalline silica.

The spicules of the calcareous sponges are usually smaller than those of the siliceous forms, and their material is not in an isotropic state, but each spicule possesses the optical characters of a crystal of calcite; consequently in polarised light these spicules are readily distinguished from unaltered siliceous forms, which appear dark between crossed Nicol's prisms. Then again the fossil calcareous spicules have undergone much less chemical change than the siliceous ones; generally they are still composed of carbonate of lime, for it is only in rare cases that this is replaced by silica. The external form of the individual calcareous spicules is, however, often less well preserved than in the case of siliceous spicules.

The forms of sponge spicules, both megascleres and microscleres, are very varied, but they can be shown to be modifications of a small number of types or fundamental forms. The spicules, on account of the constancy of their characters, are of great importance in the classification of sponges.

The canal-system is indicated in the skeleton of both recent and fossil forms, by spaces in the framework of spicules or spongin, but these spaces represent only the larger canals, the smaller existing in the soft parts alone.

Reproduction in the sponges takes places by budding and by the production of ova and spermatozoa.

Various classifications of the sponges have been proposed by different authors; in the one adopted here the divisions are based primarily on the characters of the skeleton. Three classes are recognised, (1) Hexactinellida, (2) Demospongiæ, (3) Calcarea.

CLASS I. HEXACTINELLIDA.

The spicules in the Hexactinellida (fig. 8, *f*) consist of three axes crossing at right angles to one another; in primary forms there are consequently six rays of equal length proceeding from a centre. Each ray is traversed by an axial canal, and these unite at the point of junction of the six rays. Various modifications are produced by some of the rays being longer or shorter than the others, or almost absent; and also by the branching of the rays and the occurrence of spines, knobs, etc. The spicules may remain free or they may be fused with one another by a deposit of secondary silica, but they are never united by spongin. When spicules with equal rays are united end to end, skeleton-cubes are formed, each cube consisting of eight spicules (fig. 8, *f*). Flesh-spicules are abundant, but are seldom found fossil. Some of the spicules form a layer near the external surface of the sponge for the support of the dermal membrane; others form a similar layer near the internal surface; the spicules which constitute the main part of the skeleton occur in the middle of the sponge-wall and serve to support the canals and flagellated chambers. The spicules which form the root-tuft by which many Hexactinellids are fixed, are long and thread-like. The canal-system is usually simple.

The earliest form is *Protospongia* from the Menevian Beds of St David's; *Hyalostelia* is found in the Tremadoc, and also occurs in the Ordovician, Silurian, and Carboniferous. In the Silurian the genera *Dictyophyton* and *Phormosella* are present. There are none in the Permian and Trias, but they become abundant in the Jurassic, especially in the upper part, and also in the Cretaceous; they are rare in the Tertiary. The sponge-character of the Silurian and Devonian genera *Ischadites, Receptaculites,* and *Sphærospongia,* which have been placed by some authors in this Order, is now disputed.

Protospongia. (fig. 9.) Form unknown but probably cup-shaped. Spicules cruciform, owing to the reduction of one axis, and arranged in a quadrate manner, the larger forming a framework, which contains the smaller spicules of two or three sizes, arranged in the same regular way, so that the larger squares enclose four or five series of smaller ones. The spicules were either free or probably partly fused together. Menevian Beds and Lingula Flags. Ex. *P. fenestrata.*

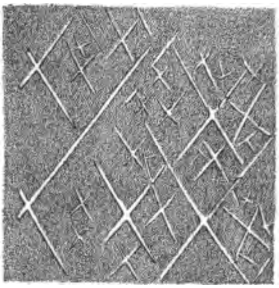

FIG. 9. ***Protospongia fenestrata,*** **Menevian Beds, St David's. × 3¾. After Hinde. The original in the British Museum. Owing to the cleavage of the rock the angles of the spicules are distorted.**

Craticularia. Cup-shaped or cylindrical; simple or branching. On both the inner and outer surfaces of the wall are circular or oval canal-openings, which are arranged in vertical and transverse rows crossing each other at right angles. Canals straight, terminating blindly. Inferior Oolite to Upper Chalk (perhaps also Miocene). Ex. *C. fittoni*, Chalk.

Ventriculites. Simple, form variable, but usually cup-shaped, funnel-shaped, or cylindrical. Central cavity large and deep. Walls folded so as to form a series of vertical grooves and ridges. Canal-system well developed; the radial canals are large and start from the central cavity, but end before reaching the outer surface; others start from the outer surface and end before reaching the central cavity. Spicules six-rayed and fused with one another so as to form a mesh-work. The node where the axes cross is hollow, having the form of a negative octahedron, the central part of each face of which is absent; the axial canals cross in the centre of the octahedral space. The sponge was provided with a root consisting of siliceous fibres. Upper Chalk. Ex. *V. radiatus*, *V. impressus*.

Plocoscyphia. Sponge formed of tubes and laminæ which anastomose, forming an irregular or rounded mass. Canal-system imperfect. Upper Cretaceous. Ex. *P. fenestrata*, Upper Greensand and Chalk Marl.

CLASS II. DEMOSPONGIÆ.

The skeleton consists of siliceous spicules, or of spongin, or of both spicules and spongin. In some forms there is little or no spongin, but in others the entire skeleton consists of spongin with no siliceous spicules; between these extremes there is a complete passage. The spicules are never of the hexactinellid type. In some few cases both spicules and spongin are absent.

ORDER 1. MYXOSPONGIDA. Sponges with no skeleton or occasionally with a few isolated spicules. Not known in the fossil state.

ORDER 2. CERATOSA[1]. Sponges with a skeleton composed of a fibrous network of spongin. This includes the ordinary bath sponges, etc., and is unknown in the fossil state.

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[1] The Orders 2 to 7 (or in some cases 3 to 7 only) are by some authors grouped together as the *Silicispongiæ*.

ORDER 3. MONAXONIDA. The skeleton is formed of spongin and spicules in varying proportions. The spicules (fig. 8, *a*) consist of a single rod or axis, which may be straight or curved, and with sharp or blunt ends; each spicule may consist of two rays or of one ray only. In the former the two ends of the spicule are alike and there is a small swelling of the axial canal at the centre of the spicule where growth commenced; in the latter the two ends are dissimilar and the swelling in the axial canal is at one end of the spicule, and growth went on in one direction only. Microscleres or flesh-spicules may also occur but are often absent. Since in this Order the spicules are only united by spongin or other decomposable material, it is extremely rare to find the form of the sponge preserved fossil; usually, detached spicules only occur.

The earliest representatives of the Monaxonida are found in the Silurian; the Order becomes more abundant in the Carboniferous, where the genus *Reniera* occurs. The freshwater form *Spongilla* is found in the Purbeck Beds of the south of England. A large number of Monaxonid sponges are still living.

ORDER 4. TETRACTINELLIDA. The spicules (fig. 8, *b*, *c*) consist of four rays given off from a common centre, the angle between the rays, when the end of one is taken as a central point, appearing to be 120°. The rays may be equal or unequal in length; frequently one is very much elongated (fig. 8, *c*), and in such forms the three shorter rays are placed near the surface of the sponge-wall and the longer ray is directed inwards. Sometimes the terminations of the rays are bifurcated. Spongin is either absent or occurs in minute quantities only, and since the spicules are not united, the Tetractinellids, like the Monaxonids, are seldom preserved in anything like a perfect condition as fossils. The oldest forms occur in the Carboniferous Limestone, where they are represented by the genera *Geodites* and *Pachastrella.*

ORDER 5. LITHISTIDA. The Lithistids have thick stony walls and very variable external form. The spicules (fig. 8, *d, e*) are stout and irregular in form, but sometimes show four rays; the extremities branch or expand, and by that means the spicules become firmly interlocked with one another, but do not fuse together. These irregular spicules (sometimes termed *desmas*) are formed by secondary silica being deposited on small spicules of the ordinary kind, which may be four-rayed or consist of a single axis. In addition to these irregular spicules there is generally a surface layer or cortex formed of trifid spicules like those in the Tetractinellids. Flesh-spicules are also present. Several different types of canal-system occur. The Lithistids are sometimes regarded as a division of the Tetractinellida.

Owing to their solidity the Lithistids are preserved abundantly as fossils. They are rare in the Palæozoic, the earliest form being *Archæoscyphia,* found in the Upper Cambrian of Canada; in the Ordovician and Silurian *Astylospongia* occurs; in the Carboniferous *Doryderma,* etc. No forms belonging to this Order have been found in the Devonian, Permian, or Trias; they are numerous in the Jurassic, attain their maximum in the Cretaceous, and are scarce in the Tertiary.

Verruculina. Irregular, fan- or funnel-shaped, attached by a short stalk. Oscula placed on prominent elevations on the upper, and sometimes also on the under surface. Spicules small, interlacing and forming a fibrous network. Ex. *V. reussi*, Upper Chalk.

Pachinion. Cylindrical or club-shaped, tapering at its lower part to a short stem. Central cavity large and deep, with vertical canals opening into its base. Wall formed of anastomosing fibres, between which are irregular spaces—there are no distinct canals; fibres formed of large spicules, branched and interlaced. There is also a surface layer composed of small spicules. Chalk. Ex. *P. scriptum*, Upper Chalk.

Scytalia. Simple, or formed of two or more individuals growing close together; cylindrical or club-shaped, with a thick wall and a cylindrical stem. Central cavity tube-like, long, continued at its base by several vertical canals; numerous radial canals open into the central cavity and taper toward the external surface. Spicules branching, with root-like prolongations. Chalk. Ex. *S. radiciformis.*

Seliscothon. Mushroom-like, consisting of a flat or concave, circular, plate-like body, and a rounded tapering stem. The circular body has rounded or oblique edges, and numerous, small, rounded oscula on the upper surface; it is formed of fine vertical radiating lamellæ, separated by spaces crossed by fibres—these spaces forming the canal-system. Spicules fine, branching irregularly, with bifurcating extremities, and covered with tubercles or spines. Chalk. Ex. *S. planus.*

Doryderma. Cylindrical, pear-shaped, sometimes branching. There are parallel vertical canals opening at the summit of the sponge, and smaller radial canals extending from the surface towards the centre. Spicules large, of various forms; also a dermal layer formed of slender trifid spicules. Carboniferous and Cretaceous. Ex. *D. benetti*, Upper Greensand.

Siphonia. (fig. 10.) Pear-shaped, usually provided with a stalk, which is given off from the broad end of the body and terminates in rootlets. The incurrent canals are small, slightly curved, and extend radially from the centre of the sponge to the surface. The excurrent canals are larger, and are arranged parallel with the surface of the sponge, extending from the base to the summit, where they open into the large central cavity by means of a series of parallel ostia. The skeletal-spicules possess four rays with bifurcated and expanded extremities, by means of which they are interlocked. Upper Greensand to Upper Chalk. Ex. *S. tulipa*, Upper Greensand.

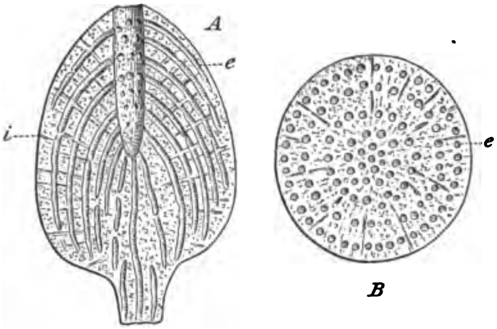

FIG. 10. *Siphonia tulipa*. Upper Greensand, Warminster. *A*, vertical section. *B*, horizontal section. *e*, excurrent canals; *i*, incurrent canals. × ⅔.

Hallirhoa. Like *Siphonia* but with the sides divided into lobes. Upper Greensand. Ex. *H. costata*.

ORDER 6. OCTACTINELLIDA. The spicules (fig. 8, *g*), consist of eight rays, six of which are in one plane diverging at equal angles, while the other two are at right angles to this plane, forming a vertical axis. Frequently, however, the vertical axis is only slightly developed or altogether absent. The spicules are not united. The only genus is *Astræospongia*, found in the Silurian and Devonian.

ORDER 7. HETERACTINELLIDA. The spicules are unusually large (fig. 8, *h*), the number of rays varying from six to thirty. The body spicules are not fused, but there is a surface layer in which the spicules are interwoven and more or less fused. The only genera are *Tholiasterella* and *Asteractinella*, found in the Carboniferous rocks of Ayrshire.

CLASS III. CALCAREA.

(CALCISPONGIÆ.)

The skeleton consists of spicules composed of carbonate of lime in the condition of calcite. The spicules are usually much smaller and less varied in form (fig. 8, *j*) than those of the siliceous sponges, and cannot be separated into megascleres and microscleres. There are three kinds, the simple uniaxial, the three-rayed, and the four-rayed; they are seldom fused with one another, and are either arranged close together so as to form fibres, or they are loosely distributed. Spongin is never present. The earliest forms in Britain occur in the Carboniferous rocks of Fifeshire.

Peronidella. Cylindrical, simple or branched; central cavity tubular and extending from the summit to the base of the sponge. Walls thick and with no definite canals, but having irregular spaces between the spicular fibres. Spicules three or four-rayed, forming anastomosing fibres. Carboniferous (possibly also Devonian) to Cretaceous; most abundant in the Jurassic and Cretaceous. Ex. *P. pistilliformis*, Great Oolite and Cornbrash.

Corynella. Form similar to *Peronidella*. Radial excurrent canals open into the central cavity, which often does not extend to the base of the sponge, but is continued downwards by vertical canals. Incurrent canals fine, directed obliquely downward. Osculum usually with radial furrows. Jurassic and Cretaceous (? Trias). Ex. *C. foraminosa*, Lower Greensand.

Holcospongia. Simple or compound: individuals usually spherical, hemispherical, or club-shaped; their summits rounded, with a central area into which a number of excurrent canals open, and from which furrows extend down the sides of the sponge. Spicules large and three-rayed, and some also filiform; and a surface layer of three-rayed spicules, of various sizes, felted together. Inferior Oolite to Cretaceous. Ex. *H. polita*, Corallian.

Elasmostoma. Leaf-like, sometimes cup- or funnel-shaped, walls thin. The upper (or concave) surface covered with a smooth dermal layer containing the openings of the oscula; under surface porous, without a dermal layer. Generally there is no canal-system. Spicules large, three-rayed, with other smaller thread-like spicules. Great Oolite to Chalk. Ex. *E. acutimargo*, Lower Greensand.

Barroisia. Usually compound and bushy. Individuals cylindrical, each divided into a series of chambers by transverse partitions, which have a central circular opening, through which a tube usually passes. Canals simple, numerous, minute. Spicules slender, three-rayed; also a surface layer of larger spicules. Lower Greensand to Chalk. Ex. *B. anastomans*, Lower Greensand.

Distribution of the Porifera.

The Sponges are all aquatic, and with the exception of the Monaxonid genus *Spongilla* and its allies, all marine. They are found in the seas of all parts of the world and are more numerous between the shore-line and 200 fathoms than at greater depths; many of the genera have a very wide distribution. All the Orders except the Octactinellida and the Heteractinellida have living representatives. The Monaxonids are abundant between the shore-line and 200 fathoms, and gradually decrease in numbers beyond that limit. The Tetractinellids also characterise water of less depth than 200 fathoms, but extend down to 2000 fathoms. The Lithistids range from 7½ to 1075 fathoms, and are most abundant between 100 and 150 fathoms, but some species occur at greater depths. The Hexactinellids occur in deeper water than the Lithistids, being found down to a depth of 2900 fathoms; but they are abundant between 100 and 200 fathoms, and again between 300 and 700 fathoms. The Calcarea are mainly shallow water forms.

The fossil forms are comparatively rare in the Palæozoic rocks until we reach the Carboniferous; and throughout the geological formations they are much less abundant in argillaceous than in calcareous and arenaceous rocks. Sponges are first found in the Lower Cambrian rocks; the earliest British form is *Protospongia* from the Menevian Beds and Lingula Flags; in the Tremadoc the Hexactinellid genus *Hyalostelia* occurs, ranging onwards as far as the Chalk. In the Ordovician we have, in the Llandeilo Beds, the first appearance of *Ischadites* (see p. 37) associated with *Hyalostelia*; in the Bala Beds we meet with *Astylospongia.* The most abundant Silurian form is *Ischadites*; *Astræospongia, Phormosella,* and *Hyalostelia* also occur. Sponges are rare in the Devonian, but *Astræospongia, Sphærospongia,* and *Receptaculites* have been recorded. In the Carboniferous rocks, sponges become much more common, the siliceous spicules often forming thick beds of chert: the Monaxonids are represented by *Reniera,* the Tetractinellids by *Geodites,* the Lithistids by *Doryderma,* the Hexactinellids by *Hyalostelia,* and the Heteractinellids by *Tholiasterella* and *Asteractinella.* Sponges appear to be absent in the Permian; and they are rare in the Trias, except in the St Cassian Beds of the Tyrol, where the Calcarea are numerous.

In the Jurassic, sponges are extremely abundant; the only Monaxonid is *Spongilla* from the Purbeck Beds; Lithistids and Hexactinellids although common in Germany and Switzerland are comparatively rare in England; the first group is represented by *Platychonia,* the second by *Craticularia, Verrucocœlia,* etc.; the Calcarea are numerous in this country as well as in France and Germany, common genera being *Peronidella, Corynella,* and *Holcospongia.* The occurrence of Hexactinellids in the

Inferior Oolite is noteworthy, since other evidence shows that that deposit was laid down in shallow water, but at the present day Hexactinellids are characteristic of deep water.

Sponges are more abundant in the Cretaceous than in any other system; in England they are found chiefly at four horizons:—(1) in the Lower Greensand of Faringdon, Upware, Kent, and Surrey, where the Calcarea are much better represented than the other groups, *Peronidella, Elasmostoma,* and *Raphidonema* being common forms: (2) in the Upper Greensand and Chloritic Marl of Warminster, Blackdown, Haldon, and the Isle of Wight, where the Lithistids (*e.g. Doryderma, Siphonia, Hallirhoa*) are very abundant, exceeding the Hexactinellids (*e.g. Craticularia, Plocoscyphia, Stauronema*); the Calcarea are also common in places: (3) in the Lower Chalk of the south of England, where we find *Siphonia, Craticularia, Stauronema, Plocoscyphia,* etc.; the Calcarea are not represented: (4) in the Upper Chalk, where the siliceous sponges are very common; amongst the Lithistids the following occur:—*Seliscothon, Verruculina, Scytalia, Doryderma,* and *Siphonia*; the Hexactinellids are represented by *Craticularia, Verrucocœlia, Guettardia, Ventriculites, Cephalites, Plocoscyphia,* and *Camerospongia*; the Calcarea are rare. In the Tertiary formations detached spicules are sometimes abundant, but few perfect sponges have been found.

PHYLUM CŒLENTERA.

Classes.	*Orders.*
1. Hydromedusæ	1. Gymnoblastea.
	2. Calyptoblastea.
	3. Graptolitoidea.
	4. Hydrocorallinæ.
	5. Stromatoporoidea.
	6. Trachomedusæ (not fossil).
	7. Narcomedusæ (not fossil).
	8. Siphonophora (not fossil).
2. Scyphomedusæ	1. Stauromedusæ (not fossil).
	2. Peromedusæ (not fossil).
	3. Cubomedusæ (not fossil).
	4. Discomedusæ.
3. Anthozoa or Actinozoa	1. Zoantharia.
	2. Alcyonaria.
4. Ctenophora (not fossil).	

THE Cœlentera include hydroids, jelly-fishes, sea-anemones, corals, and allied forms. The individuals are radially symmetrical, and have only one internal cavity, the *cœlenteron,* which opens to the exterior by the mouth. The body-wall consists of an outer layer of cells, the *ectoderm,* and an inner layer, the *endoderm*; between these is a gelatinous layer—usually quite thin, but in the jelly-fishes of considerable thickness. Stinging cells known as nematocysts or thread-cells are generally present in the ectoderm. The canal-system, so characteristic of the sponges, is absent.

This Phylum is divided into four classes, (1) Hydromedusæ, (2) Scyphomedusæ or Acalephæ, (3) Anthozoa or Actinozoa, (4) Ctenophora. The first two classes have usually been grouped together as the Hydrozoa; but the Scyphomedusæ are now regarded as more closely related to the Anthozoa than to the Hydromedusæ. The Ctenophora have not been found fossil.

CLASS I. HYDROMEDUSÆ.

The simplest type of the Hydromedusæ is the common freshwater *Hydra.* In this the body has the form of an elongated sac, about a quarter of an inch in length, and is attached by one end, whilst at the other is the mouth surrounded by a row of long processes, called *tentacles.* The large undivided cavity in this sac, which opens into the hollow tentacles above, is the cœlenteron. The whole body is very contractile and constantly changing its shape. Reproduction may take place in three ways, (1) by the growth of buds, which ultimately separate from the parent, (2) sexually, by the production of ova and spermatozoa in the ectoderm, and (3), in rare cases, by fission.

Other Hydromedusæ consist of a number of individuals (polyps or hydranths) having practically the same structure as *Hydra,* but growing together as a colony (fig. 11); all the individuals in such cases are placed in living communication by means of a tube-like extension from the base of each polyp; this common connecting portion of the colony is called the *cœnosarc* (fig. 11, 5). Frequently the cœnosarc is much branched, giving rise to tree-like forms; it is usually attached to some foreign object by a horizontal branching portion.

In such hydroid colonies the polyps are asexual, and the reproductive elements are produced in another individual of a somewhat different character, known as a *medusa* or *gonophore*: this arises by budding from the hydroid (fig. 11, 9), and is often more or less bell-shaped, and may become detached from the colony, or it may be less perfectly developed and remain attached; at the inner edge of the bell is a shelf-like fold, the *velum*. The generative cells are of ectodermal origin, and from them the hydroid developes.

Hydra possesses no hard parts, but in other forms an external skeleton composed of chitin or of carbonate of lime is secreted; it commonly forms a tube-like sheath around the cœnosarc and is called the *perisarc* (fig. 11, 6). In one group the perisarc is produced at the base of each polyp into a cup-like structure or *hydrotheca* (fig. 11, 7), into which the polyp can retract. The gonophores may also be protected by a chitinous capsule called the *gonotheca* or *gonangium* (fig. 11, 10). The vertical branching part of the cœnosarc together with the perisarc around it, is called the *hydrocaulus*; the horizontal root-like portion and its perisarc form the *hydrorhiza*.

The principal characters which distinguish the Hydromedusæ from the other Cœlenterates are: the cœlenteron being undivided by radial partitions or ridges; the absence of a digestive tract projecting into the cœlenteron; the usual occurrence of an asexual (hydroid) generation alternating with a sexual (medusoid) generation; the medusa having a velum; the ova and spermatozoa being derived from the ectoderm.

Nearly all the Hydromedusæ are marine. They are divided into eight Orders, of which five occur fossil:—(1) Gymnoblastea, (2) Calyptoblastea, (3) Graptolitoidea, (4) Hydrocorallinæ, (5) Stromatoporoidea.

ORDER I. GYMNOBLASTEA.

The Gymnoblastea have no hydrothecæ into which the polyps can retract; gonangia (gonothecæ) are also absent.

Well-known living forms are *Tubularia*, *Bougainvillea*, and *Hydractinia*. The last has been found fossil in Eocene and later deposits; it forms a crust over the shells of gasteropods, especially those tenanted by Hermit-crabs. The hard part of this crust is chitinous, or rarely calcareous, and consists of laminæ separated by irregular or cubical spaces and crossed by vertical pillars; on the surface are projecting spines. The soft parts form a layer over this skeleton, and consist of a sheet of ectoderm on the surface, and another sheet next the skeleton; between these are branching and anastomosing cœnosarcal tubes. The skeleton is secreted by the lower ectoderm. From the cœnosarc arise the polyps, which are placed on long vertical stalks and are of four kinds, (1) gastrozooids—the ordinary nutritive individuals, (2) blastostyles, which are individuals specially modified for bearing medusæ, (3) dactylozooids—individuals modified for catching prey and having short knob-like tentacles crowded with nematocysts, (4) tentacular polyps, which are very slender, without a mouth, and occur near the edge of the colony.

Parkeria, which is found in the Cambridge Greensand, probably belongs to this Order. A few other forms have been described from the Alpine Trias and the Jurassic of southern Europe.

ORDER II. CALYPTOBLASTEA.

This Order is distinguished by the presence of hydrothecæ and gonangia (gonothecæ). (Fig. 11, 7, 10.)

The arrangement of the polyps and hydrothecæ on the hydrocaulus varies considerably in different genera. Some-

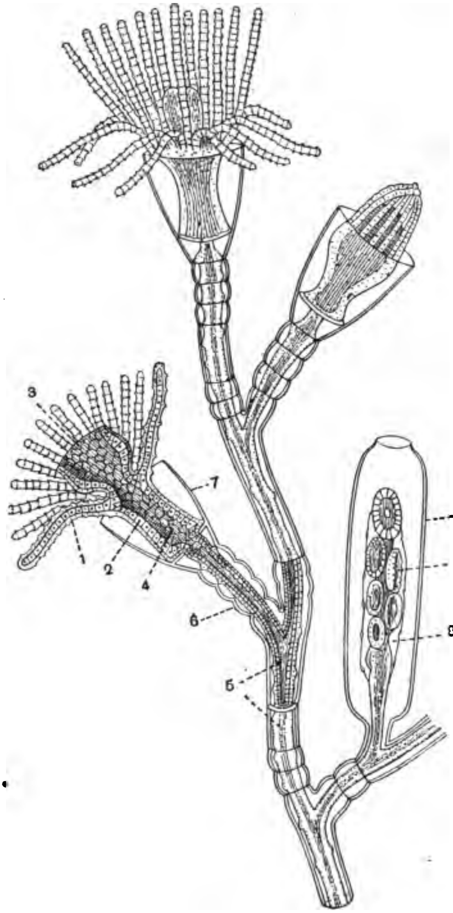

FIG. 11. Part of a branch of *Obelia*. Enlarged. To the left a portion is shown in section. (After Parker and Haswell.) 1, ectoderm; 2, endoderm; 3, mouth; 4, cœlenteron; 5, cœnosarc; 6, perisarc; 7, hydrotheca; 8, blastostyle, a mouthless polyp bearing medusa-buds; 9, medusa bud; 10, gonangium or gonotheca.

times they are placed on stalks as in *Obelia* (fig. 11) and *Campanularia*; in many others they are sessile. They may be in rows or placed in various positions on the hydrocaulus. In *Plumularia*, *Aglaophenia*, etc., they form a single row; in *Sertularia*, etc. there are two rows placed on opposite sides of the branches. Sometimes the hydrothecæ are close together, but more usually separated.

In the Plumulariidæ there are, in addition to the ordinary polyps, others which are solid and tentacle-like; they are usually provided with nematocysts and are called *nematophores*; each one is placed in a hydrotheca.

Although the Calyptoblastea possess a well-developed chitinous skeleton, yet, with the exception of a form found in the Pleistocene, they are not definitely known to occur as fossils. In the Lower Palæozoic, however, there are organisms (usually termed 'dendroid graptolites') which present considerable resemblance to the Calyptoblastic hydroids; the best known are *Dendrograptus*, *Ptilograptus*, *Dictyonema*, and *Callograptus*. These are usually much branched and tree-like, and are fixed by a root-like structure; hydrothecæ occur, but no virgula is found. Transverse sections of *Dictyonema* and *Dendrograptus* show that some of the branches consist of a group of tubes of various sizes, somewhat resembling in this respect the recent forms *Clathrozoon* and *Grammaria*.

Dictyonema (= *Dictyograptus*) is found in the Cambrian, Ordovician, and Silurian, and has a fan- or funnel-shaped skeleton which consists of numerous radiating branches, placed nearly parallel with one another, and united by transverse fibres. *Dendrograptus* occurs in the Ordovician, *Callograptus* in the Arenig, and *Ptilograptus* ranges from the Arenig to the Ludlow Beds.

ORDER III. GRAPTOLITOIDEA.

The graptolites are found only in the Lower Palæozoic rocks, where, owing to their abundance and to the limited range in time of both genera and species, combined with their wide geographical distribution, they are of great importance to the stratigraphical geologist. They occur most commonly in argillaceous rocks, especially in black shales, whilst they are rare in sandstones and limestones. The graptolites resemble the Calyptoblastea, *e.g.* *Sertularia* and *Plumularia*; they were compound animals, consisting of a number of individuals or polyps united by a common cœnosarc, the whole being protected by a skeleton of chitin. But the original material of the skeleton is seldom preserved unaltered; it has usually become carbonised or replaced by iron pyrites. The entire skeleton (exclusive of the soft parts) is termed the *polypary*; this in an unbranched form like *Monograptus* consists of a more or less cylindrical tube known as the *common canal* (fig. 12 b, *c*), which extends nearly the whole length of the animal, the wall being termed the *periderm* or perisarc. From one side of the common canal small cups or tooth-like projections are given off; these are the *hydrothecæ* (fig. 12 b, *h*), each of which opens on the one hand into the common canal and on the other to the exterior; the latter aperture, known as the *mouth* (*m*) of the hydrotheca, is frequently circular, but sometimes quadrangular or slit-like. Embedded in the periderm on the side opposite to the row of hydrothecæ is a chitinous thread or rod, termed the *virgula* (fig. 12 d, *a*); in some cases this is solid, in others it appears to be hollow. In some species of *Monograptus* the virgula projects beyond

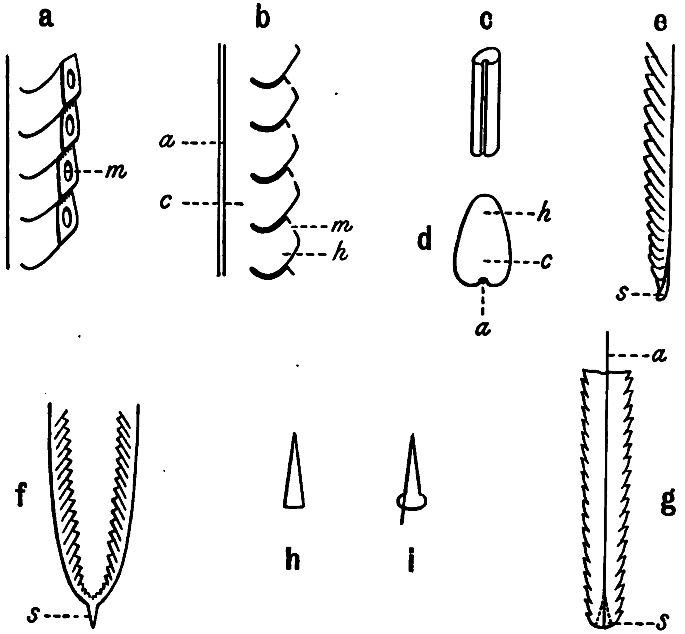

FIG. 12. Morphology of Graptolites. a, Portion of *Monograptus personatus*; b, vertical section of the same; c, *Monograptus*, showing a groove on the dorsal surface which was produced by the removal of the virgula; d, transverse section of *Monograptus* with virgula (N.B. Recent work has shown that the virgula is actually embedded in the periderm and *not* placed in a groove); e, *Monograptus colonus*, Coniston Grits, with sicula (*s*); f, *Didymograptus murchisoni*, Llandeilo Beds; g, *Diplograptus foliaceus*, Llandeilo Beds, with the position of the embedded sicula (*s*) indicated; h, sicula of *Diplograptus*, the earliest stage; i, the same with virgula and two buds developed. (All enlarged except f.)

a, virgula; *c*, common canal; *h*, hydrotheca; *m*, mouth of hydrotheca; *s*, sicula.

the distal[1] end of the common canal. At the proximal end of the polypary there is a small conical body, termed the *sicula* (fig. 12 e, *s*), which will be described more fully below.

The soft parts of the graptolites are of course unknown, but from comparison with living hydroids which have a similar skeleton, we may consider it probable that each hydrotheca lodged an individual polyp, and that these were connected by means of the cœnosarc which occupied the common canal.

In the form just described (*Monograptus*) the polypary is always simple, but in many genera it consists of two or more branches or stipes. When several branches are given off from a common centre their proximal parts are sometimes enclosed in a horny sheath, termed the *central disc*, as in some species of *Tetragraptus* (fig. 13). In those genera which have two branches (fig. 12 f), the term *angle of divergence* is applied to the angle between the hydrothecal margins. In some cases (*e.g.* *Monograptus*, fig.

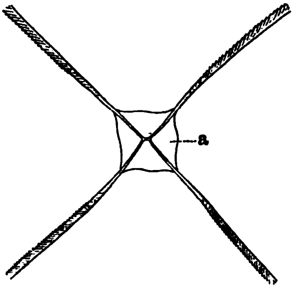

FIG. 13. *Tetragraptus headi*, Arenig Rocks. *a*, central disc. × ½.

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[1] The proximal end is that which in recent hydroids is attached; the distal is the free end. In the graptolites the proximal end is formed first, the distal end last.

12 e) the polypary possesses only a single row of hydrothecæ, such forms are said to be *monoprionidian*; others however (*e.g. Diplograptus*, fig. 12 g) possess two rows on opposite sides of the polypary—these are the *diprionidian* forms, and they may have a single common canal as in *Retiolites*, or there may be two canals separated by a septum, as in *Climacograptus*: in many forms of *Diplograptus* there is only one common canal, but others possess an imperfect septum which, to some extent, divides the canal into two parts. The genus *Dicranograptus* shows a transition between the monoprionidian and the diprionidian types, its proximal end being provided with two rows of hydrothecæ, whilst distally the polypary divides into two branches, each bearing a single row. In *Dimorphograptus*, on the other hand, the proximal part is monoprionidian and the distal part diprionidian; this genus therefore serves to connect *Diplograptus* and *Monograptus*.

The hydrothecæ vary considerably in form in different genera, and sometimes even in different species of the same genus; but in any one species they are similar, except that they diminish in size towards the proximal end of the polypary; they may be rectangular (*Phyllograptus*), tubular (*Rastrites*), conical (*Monograptus spiralis*), or coiled (*Monograptus lobiferus*). They may be in contact throughout their entire length (*Phyllograptus*), at their bases only (*Cœnograptus*), or, in a few cases, entirely separate (*Rastrites*). Frequently they are provided with one or more spines near the mouth. In most graptolites the hydrothecæ communicate freely with the common canal, and in this respect differ from living hydroids, in which there is a constriction or an imperfect diaphragm at the base of each hydrotheca, separating it from the common canal (fig. 11). But McCoy and Hopkinson have described specimens of *Didymograptus* and *Tetragraptus*, from the Skiddaw Slates, in which there is a distinct septum between each hydrotheca and the common canal, and also in some cases the common canal itself is divided up by transverse septa. On account of the free communication between the hydrothecæ and the common canal, Allman thought that all the polyps of the graptolites were probably nematophores (see p. 52), and that the ordinary nutritive polyps were absent; a similar condition is found in certain Plumulariidæ, where some branches bear nematophores only. Further, in the young stages of some Plumulariidæ, nematophores only occur, the ordinary polyps appearing subsequently.

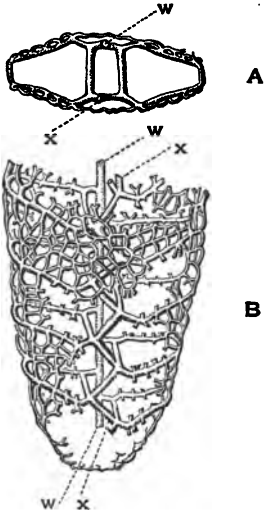

FIG. 14. *Retiolites geinitzi*, Silurian. A, section across polypary. B, proximal end of polypary with the outer layer removed. Enlarged (after Holm). *w*, virgula. *x* zigzag rod.

A microscopic examination of thin sections of *Monograptus* shows that the periderm consists of four layers, the external and internal layers being much thinner than the two others. In *Retiolites* the periderm is formed of a network of fibres (fig. 14) covered by a continuous outer layer or epiderm.

In the monoprionidian genera the virgula, when present, is placed in the periderm opposite the row of hydrothecæ, but in the diprionidian forms it is central, being situated either in the middle of the common canal, as in some forms of *Diplograptus*, or in the septum separating the two canals, as in *Climacograptus*. In *Retiolites* the virgula (fig. 14 *w*) is placed in the wall on one side of the common canal between the two rows of hydrothecæ, and in the opposite wall there is a zig-zag thickening in the periderm which has usually been described as a second virgula (fig. 14 *x*). In several genera (*Didymograptus*, *Phyllograptus*, *Tetragraptus*, *Dichograptus*, *Dicranograptus*, and *Dicellograptus*) there is no virgula in the wall of the common canal; but sometimes there is a thread-like prolongation of the pointed end of the sicula which appears to represent the virgula. The position of the sicula also varies in different genera. In *Monograptus* it is united to the dorsal surface of the polypary, the pointed end being directed distally (fig. 12 e, *s*). In *Diplograptus* it has a similar position but is enclosed between the hydrothecæ (fig. 12 g, *s*). In *Didymograptus* its broad end only is united to the two branches of the polypary, the pointed end being directed proximally (fig. 12 f, *s*). In *Dicellograptus* it projects as a spine between the two branches.

The appearance of even the same species of graptolite varies considerably according to its mode of preservation. Frequently it is flattened to a film, and when this is the case we may get a side view, a front view showing the mouths of the hydrothecæ, or a back view; in the two latter cases the margins will be parallel. But when the original material has been replaced by iron pyrites, or when the graptolite is preserved in a limestone, the natural form of the polypary is retained.

No medusoid form is known in the graptolites; but, in one respect, their mode of reproduction appears to have been similar to that which takes place in some living Hydromedusæ. In a few diprionidian graptolites (fig. 15) sac-like bodies have been found attached to the sides of the polypary; these, when perfect, are pear-shaped, and in some cases at any rate are connected with the virgula by means of fibres. These sacs resemble the *gonangia* of living Calyptoblastea (see fig. 11, 10), but they spring direct from the hydrothecæ which, with one exception (*Synthecium*), is not the case in living forms. The earliest condition of the graptolite at present known is the *sicula* (fig. 16 A); this probably is developed within the sac-like bodies which are supposed to be gonangia.

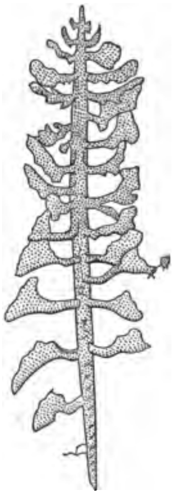

FIG. 15. *Diplograptus whitfieldi*, with reproductive sacs. (After Hall.) Natural size.

The mode of development of the graptolite from the sicula has been carefully studied in the genera *Monograptus* and *Diplograptus* (fig. 16). The sicula is a hollow cone open at the base; it consists of two parts—the pointed end with a thin wall (*b*), and the broader basal part with a thick wall marked with lines of growth (*a*). The pointed part was probably the covering of the embryo, and the broad part a later growth. In *Monograptus* a bud, which developes into the first hydrotheca (fig. 16 B, 1), arises on one side of the sicula; and from this the second hydrotheca (2) is given off: each subsequent hydrotheca is produced in the same way from the one preceding.

In *Diplograptus* one bud only is given off from the sicula; this becomes the first hydrotheca (fig. 16 C, 1); from this the second hydrotheca (2), which is on the opposite side, is given off; the later hydrothecæ (3, 4, etc.) arise from the one preceding on the opposite side: when this mode of development continues the common canal is very small and remains undivided; but in some cases after the first few hydrothecæ have been formed in this way on alternate sides, the later ones arise from the preceding hydrotheca

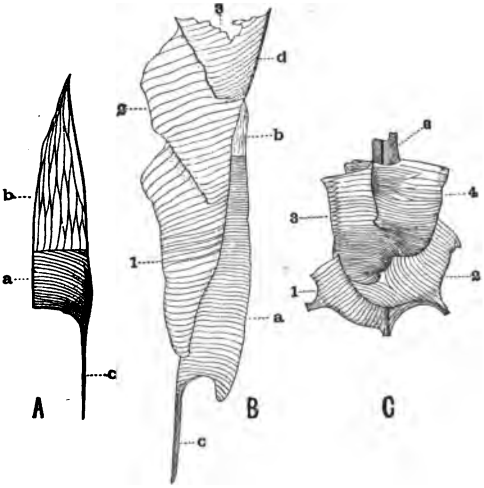

FIG. 16. Early stages of *Monograptus* and *Diplograptus* (after Wiman). Enlarged.

A. Sicula of *Monograptus*, from the Silurian of Gothland. *a*, thick-walled part with lines of growth; *b*, the earliest part with a thin wall; *c*, virgula.

B. *Monograptus* (same locality) with three hydrothecæ developed. 1, 2, 3, first, second, and third hydrothecæ; *a*, *b*, sicula; *c*, *d*, virgula.

C. *Diplograptus* from Bornholm, with four hydrothecæ developed. 1, 2, 3, 4, first, second, third and fourth hydrothecæ; *a*, sicula.

on the *same* side, and when this takes place a septum, dividing the common canal longitudinally, is formed between the two rows.

When, as in many forms of *Diplograptus*, the virgula projects beyond both ends of the polypary, it is not, as has usually been stated, a continuous rod, but consists of two distinct parts *c*, *d* (fig. 16 B); the distal part has grown out as a spine from the pointed end of the sicula, but the proximal part has been formed independently at the broad end.

Owing to the fact that the soft parts of the graptolites are entirely unknown it is difficult to speak of their affinities with any degree of certainty. There seems but little doubt, however, that they belong to the Hydromedusæ; Allman and others consider them to be closely related to the Calyptoblastea, especially to such forms as *Sertularia* and *Plumularia*, with which they agree in the general characters of the hydrothecæ and common canal, and probably also in the possession of gonangia. But they differ from the Calyptoblastea in possessing a virgula and sicula, in the diminution in size of the hydrothecæ towards the proximal end of the polypary, in the hydrothecæ being nearly always in contact, and in the free communication which exists in many cases between the hydrothecæ and the common canal; their development is also different—in the graptolites each hydrotheca is budded off from another hydrotheca, but in the Calyptoblastea the new polyps are budded off from the cœnosarc. Further, the graptolites never form the much-branched tree-like colonies which occur so commonly in recent hydroids, and the graptolites are never firmly fixed by any root-like structure corresponding to the hydrorhiza.

Some authors have considered that the graptolites were free-swimming animals; but it is very probable that some, at any rate, were attached to sea-weeds or other foreign objects by means of a thread which, in a number of cases, has been found coming off from the sicula; if they were fixed to floating sea-weeds their wide geographical distribution would be readily accounted for. Ruedmann has recently described specimens of *Diplograptus pristis* (fig. 17), from the Utica Slate (Ordovician) of New York, which consist of a number of individuals radiating from a centre where they join by the distal prolongations of their virgulas; at the point of union there is a small, nearly square, chitinous sheath which is similar in appearance to the central disc of *Tetragraptus*, etc.; below this is a larger quadrate body, apparently vesicular, which was at first regarded as a float

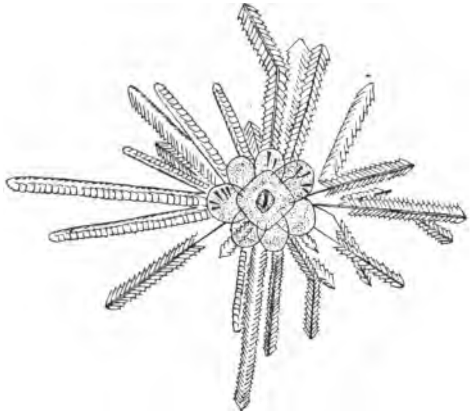

Fig. 17. *Diplograptus pristis*, **from the Utica Slate, New York. × ⅔. (After Ruedmann.)**

or pneumatocyst, but later as probably an organ of fixation at the base of the colony. Around the small disc are from four to eight globular vesicles, which Ruedmann considers to be gonangia, since they contain siculæ; the siculæ sometimes pass out and develope into fresh colonies, but in other cases they remain attached to the parent, and, by the growth of the virgula, extend outwards, and subsequently hydrothecæ arise in the usual way. In some other species of *Diplograptus* (*D. vesiculosus*, etc.) a single vesicle is sometimes found attached to the distal end of the virgula.

The genera of graptolites at present accepted are based, to a large extent, on the number of branches of the polypary; but Nicholson and Marr consider that this feature is of less importance than was formerly supposed, and that a classification which shows the genealogical relationships of the forms should be founded chiefly on the characters of the hydrothecæ and, to some extent, on the angle of divergence of the branches. The early graptolites, such as *Bryograptus*, appear, at first sight, to be more complex than the later types (*e.g. Monograptus*), on account of their more complex branching; but in the early forms the hydrothecæ are very simple, differing but little from the sicula, whereas in the later ones they exhibit considerable modification. In some genera the hydrothecæ of different species show great variety of form, those of one species being often much more like those of a species belonging to another genus than to other species of the same genus: thus we get the same type of hydrotheca in the three forms *Bryograptus callavei*, *Tetragraptus hicksi*, and *Didymograptus affinis*, and another type in *Bryograptus retroflexus*, *Tetragraptus denticulatus*, and *Didymograptus fasciculatus*. It is contended that each of these groups is a genealogical series and should be regarded as a genus—that *T. hicksi* has descended from *B. callavei*, and *D. affinis* from *T. hicksi*. According to the old view all the species of *Didymograptus* were thought to have descended from one common ancestor; but this will not account for the close resemblance which the hydrothecæ of certain species of *Didymograptus* bear to those of certain species of *Tetragraptus*; on the other hand, this is readily explained if we consider that the species of *Didymograptus* have descended from various species of *Tetragraptus*. Then again, the remarkable diversity in the hydrothecæ of *Monograptus* can be easily understood if we grant that the forms included under this term are the descendants of different species of one or more genera. But since species which have a different ancestry cannot be placed in the same genus, we must regard *Monograptus* as an assemblage of forms which simply agree in consisting of a single monoprionidian branch or stipe.

It has been suggested that the similar modification in branching found in different forms may have been brought about by the necessity of obtaining sufficient food—the larger the number of branches the smaller would be the total supply of food for each individual of a colony; consequently, when one species of a four-branched type (*Tetragraptus*) had become a two-branched form, it would have a considerable advantage over the remaining four-branched forms, which would, as a result, soon die out.

Didymograptus. (fig. 12 f.) Polypary bilaterally symmetrical, monoprionidian, consisting of two branches diverging at an angle which varies, in different species, from 0° to 180° (or occasionally more). Hydrothecæ rectangular, in contact. Pointed end of sicula directed proximally. Lower Arenig to Upper Llandeilo. Ex. *D. murchisoni*, Lower Llandeilo; *D. patulus*, Arenig.

Phyllograptus. (fig. 18.) Polypary leaf-like, formed of four branches united along the whole of their length and placed at right angles to one another. Hydrothecæ rectangular, in contact throughout their entire length, and furnished with two strong spines. Sicula pointing distally. Arenig. Ex. *P. typus*, Lower Arenig.

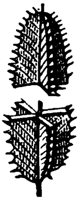

FIG. 18. *Phyllograptus*, Arenig Rocks. The polypary has been cut in two, and the upper part raised so as to show the four branches. Natural size.

Tetragraptus. (fig. 13.) Polypary bilaterally symmetrical, monoprionidian, consisting of four simple radiating branches which arise from the bifurcation of two short branches coming off from opposite sides of the sicula. Hydrothecæ rectangular, in contact. A central disc may or may not be present. Lower Arenig. Ex. *T. quadribrachiatus.*

Dichograptus. Polypary consisting of four monoprionidian branches which soon bifurcate. Hydrothecæ rectangular. A central disc is frequently present. Lower Arenig. Ex. *D. octobrachiatus.*

Loganograptus (Arenig) and *Clonograptus* (Tremadoc and Arenig) are allied to *Dichograptus.*

Bryograptus. Polypary bilateral, monoprionidian, consisting of two primary branches diverging (generally at a small angle) from a distinct sicula, which has its point directed distally and often prolonged into a thread. From the inner margins of the primary branches secondary branches (which may bear other branches) arise at irregular intervals. Tremadoc. Ex. *B. kjerulfi.*

Leptograptus. Polypary consisting of two simple, slender, flexuous, monoprionidian branches, given off in opposite directions from the broad end of the sicula. Upper Llandeilo to Lower Bala. Ex. *L. flaccidus*, Upper Llandeilo and Lower Bala.

Pleurograptus. Two principal branches as in *Leptograptus*; these bear secondary branches on both sides, often arising alternately, and sometimes bearing smaller branches. Lower Bala. Ex. *P. linearis.*

Cœnograptus. Polypary bilateral, monoprionidian, consisting of a central portion bent into an S-shape, giving off branches from the convex margins. Hydrothecæ in contact only, not overlapping. Sicula triangular, placed at the centre of the polypary. Upper Llandeilo. Ex. *C. gracilis.*

Dicranograptus. Polypary diprionidian in the proximal portion, dividing distally into two monoprionidian branches. Terminations of the hydrothecæ isolated and incurved. Upper Llandeilo to Lower Bala. Ex. *D. clingani*, Bala.

Dicellograptus. Like *Dicranograptus*, but monoprionidian throughout, the two branches united by the sicula only, which points distally. Angle of divergence greater than 180°. Upper Arenig to Upper Bala. Ex. *D. anceps*, Upper Bala.

Diplograptus. (fig. 12 g.) Polypary diprionidian. Hydrothecæ overlapping and placed obliquely. Virgula prolonged beyond the distal and sometimes also the proximal extremity of the polypary. Sicula embedded, pointing distally. Lower Arenig to Tarannon. Ex. *D. foliaceus*, Llandeilo to Lower Bala. *Petalograptus* and *Cephalograptus* are sub-genera; Llandovery and Tarannon.

Climacograptus. Polypary diprionidian. Hydrothecæ placed vertically and separated by deep depressions. Virgula prolonged beyond both extremities. Lower Arenig to Tarannon. Ex. *C. normalis*, Llandovery and Tarannon.

Dimorphograptus (see p. 56). Llandovery.

Monograptus. (fig. 12 e.) Polypary unbranched, monoprionidian, straight, curved or spiral. Hydrothecæ vary in form in different species. Sicula attached to the proximal end of the polypary, and its pointed end directed distally. Lower Llandovery to Lower Ludlow. Ex. *M. nilssoni*, Lower Ludlow; *M. leptotheca*, Llandovery; *M. priodon*, Wenlock; *M. spinigerus*, Llandovery.

Rastrites. Similar to *Monograptus*, but the common canal is very narrow, and the hydrothecæ are long, tubular, and widely separated. Llandovery to Tarannon. Ex. *R. peregrinus*, Llandovery to Tarannon.

Cyrtograptus. Similar to *Monograptus*, but coiled into a plane spiral with branches given off from the external (hydrothecal) margin. Upper Tarannon to Lower Ludlow. Ex. *C. murchisoni*, Wenlock Shale.

Retiolites. (fig. 14.) Polypary simple, diprionidian, narrower at the ends. Hydrothecæ rectangular, alternating, given off from a single common canal. Inner layer of the periderm consists of a network of rods or threads. Virgula placed in the wall on one side of the common canal; in the opposite wall is a zig-zag rod in the inner layer of the periderm. Lower Bala to Wenlock. Ex. *R. geinitzianus*, Upper Tarannon and Wenlock.

Distribution of the Graptolitoidea.

In Britain the earliest graptolites occur in the Tremadoc Beds, where we find the genera *Bryograptus* and *Clonograptus*; in the *Olenus*-shales of West Gothland *Dichograptus* also occurs. The last two forms are also present in the lower part of the Arenig Beds, but other genera such as *Tetragraptus* and *Didymograptus* are associated with them and soon become abundant; *Phyllograptus* also occurs here. In the Llandeilo, the graptolites are transitional between the Arenig and Bala forms, *Phyllograptus* is absent, *Didymograptus* is fairly common in the lower part, and the genera *Dicellograptus, Dicranograptus, Diplograptus* and *Climacograptus* now appear for the first time. In the Bala Beds, the four last-mentioned genera become much more abundant, and with them occur *Leptograptus* and *Pleurograptus.* The only genera which pass up from the Bala to the Silurian are *Climacograptus, Diplograptus,* and *Retiolites*; not a single Bala species (except perhaps a variety of *Climacograptus scalaris*) is found in the Llandovery Beds, so that between the Ordovician and Silurian there is a great break in the graptolitic succession. As a whole, the Silurian formations are characterised by the presence of the family *Monograptidæ*[1], which appears first at the base of the Llandovery Beds. In the lower part of the Llandovery the genera *Diplograptus* and *Climacograptus* are fairly abundant, but they become extinct in the Tarannon, and in the Wenlock and Ludlow Beds the only forms are *Monograptus*, *Cyrtograptus*, and *Retiolites*. The last traces of graptolites occur in the Downtonian Beds, but they are too imperfect for determination.

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[1] This includes the genera, *Monograptus*, *Rastrites* and *Cyrtograptus*.

ORDER IV. HYDROCORALLINÆ.

The skeleton in the Hydrocorallinæ is calcareous and has the form of encrusting or branching masses. It consists of a network of rods, in which there are tubes of two sizes opening on the surface; the larger are called *gastropores*, and have horizontal partitions or tabulæ; the smaller are named *dactylopores*. The skeleton is of ectodermal origin, and is secreted by a network of cœnosarcal tubes, above which is a superficial layer of ectoderm. The polyps project above this layer, and are of two kinds: nutritive individuals or gastrozooids, which are placed in the gastropores, and dactylozooids placed in the dactylopores.

Millepora is an important rock-building organism at the present day, often contributing largely to the formation of coral-reefs; it has been recorded from Cainozoic deposits, but whether these examples really belong to that genus appears to be somewhat doubtful. *Stylaster* is also a living form, and is stated to occur in the Miocene. *Millestroma* from the Cretaceous of Egypt may belong to this Order.

ORDER V. STROMATOPOROIDEA.

In the Stromatoporoids the skeleton is calcareous[1], and very variable in form; it may be hemispherical, spheroidal, dendroid, encrusting, or altogether irregular, and frequently forms large masses. It consists of a series of concentric laminæ separated by spaces; these are crossed at right angles by rods or pillars, which give off horizontal processes at definite intervals; these processes join together and really form the laminæ. The under surface of the skeleton is often covered by a thin imperforate layer, with concentric furrows, similar to the epitheca of many compound corals. On the upper surfaces of the laminæ there are, in many forms, shallow grooves, having a stellate arrangement, and known as *astrorhizæ.* In some genera, as for example *Actinostroma* (fig. 19), the two elements of the skeleton, the laminæ and pillars, remain quite distinct, but in others, like *Stromatopora*, they become to a great extent blended together so as to form a more or less netted structure; between these two types, however, there are intermediate forms. The first type (*Actinostroma*) is similar to *Hydractinia* (see p. 50), but is always calcareous and forms larger masses; the second (*Stromatopora*) resembles *Millepora* (see p. 68), and, like that genus, possesses tubes with horizontal partitions, but the tubes seem to be of one size only, and consequently there is nothing to indicate that this type was dimorphic; it differs also in possessing radial pillars.

The soft parts in the Stromatoporoids probably formed a continuous layer on the surface of the skeleton, and the polyps in some cases (*e.g. Stromatopora*) were placed in definite tubes, but in others tubes are absent and there are pores only in the external lamina. From the structure of the skeleton, the Stromatoporoids seem to be connected with both *Hydractinia* and the Hydrocorallinæ.

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[1] In some specimens the carbonate of lime has been dissolved and its place taken by silica.

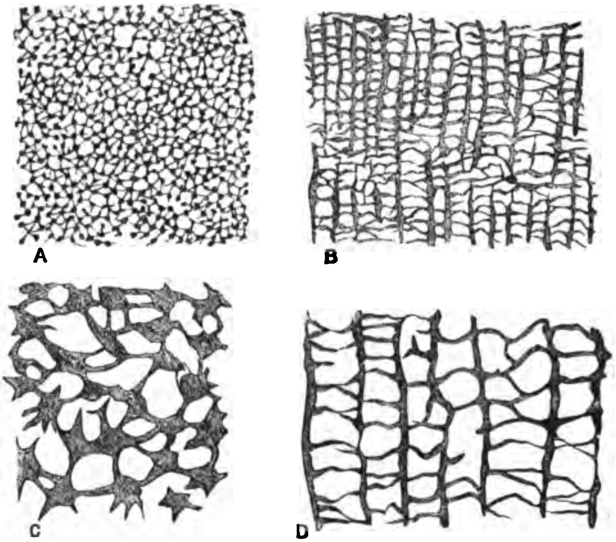

FIG. 19. A, Tangential section of *Actinostroma intertextum* showing the radial pillars. B, vertical section showing the radial pillars and the formation of the concentric laminæ by processes given off from these. × 12. C and D, parts of the same further enlarged. From the Silurian Rocks. (After Nicholson.)

The Stromatoporoids are found only in the Ordovician, Silurian, and Devonian Systems, being most abundant in the last; frequently they are of considerable importance as rock-builders. Some of the best known genera are *Labechia, Stromatopora, Stromatoporella, Actinostroma, Clathrodictyon, Idiostroma,* and *Amphipora.*

CLASS II. SCYPHOMEDUSÆ.

The Scyphomedusæ or Acalephæ include the larger and more conspicuous jelly-fishes, such as *Aurelia, Rhizostoma,* and *Pelagia.* They possess no hard parts; nevertheless the impressions of some forms (*e.g. Rhizostomites*) belonging to the Order Discomedusæ have been found in the Lithographic Limestone (Upper Jurassic) of Solenhofen.

Even in the oldest fossiliferous formations traces o supposed Scyphomedusæ have been found; the most satisfactory of these is the form from the Lower Cambrian of Sweden referred to the Discomedusæ, and named *Medusina costata* (= *Medusites lindstrœmi*). Others, but of which the nature appears to be somewhat doubtful, have been described by Walcott from the Middle Cambrian of Alabama.

CLASS III. ANTHOZOA (ACTINOZOA).

This Class includes the corals and sea-anemones. They differ from the Hydromedusæ (1) in possessing an œsophageal tube, which is distinct from the cœlenteron, though opening into it; (2) in having the cœlenteron divided up into chambers by vertical radiating partitions known as mesenteries; (3) in the reproductive elements being developed in the endoderm of the mesenteries and never on a medusa.

The Anthozoa possess an apparent radial symmetry, but closer examination reveals a bilateral arrangement of their parts. In a typical form, such as the common sea-anemone or a simple coral (fig. 20), the body has a more or less cylindrical shape, and is attached by one end, the other having an opening, the mouth (fig. 20, 2), surrounded by tentacles (1). The mouth leads into the *œsophageal tube* or *stomodæum* (3), which opens at its lower end into the cœlenteron. The latter is divided into chambers by radiating partitions, the *mesenteries* (fig. 20, 4 and fig. 21 *a*—*c*), each of which consists of a thin gelatinous layer in the middle and a layer of endoderm on each side. In the upper part of the polyp the inner edges of the principal mesenteries join the œsophageal tube, but in the lower part they remain free, and a section in the former region (fig. 21) will show the body wall and also the

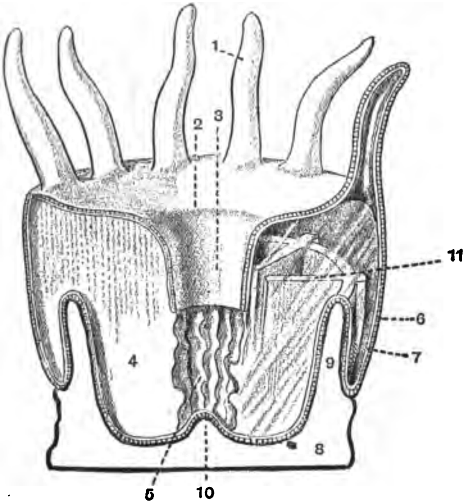

Fig. 20. Semi-diagrammatic view of half a simple Coral. (Partly after Bourne.) On the right side the tissues are represented as transparent to show the arrangement of the theca and septa; on the left a mesentery is seen. 1, tentacle; 2, mouth; 3, œsophagus; 4, mesentery; 5, mesenteric filaments, free edge of mesentery; 6, ectoderm; 7, endoderm; 8, basal plate of skeleton; 9, theca; 10, columella; 11, septum.

œsophageal wall, but in the latter the body wall only. The tentacles (fig. 20, 1) are placed immediately above the intermesenteric chambers, and the space in each tentacle is continuous with that of the chamber below. A bilateral symmetry is indicated by the oval or slit-like mouth, and the similarly compressed stomodæum; also by the arrangement of the longitudinal muscles which occur on one face of each mesentery, extending from the base of the polyp upwards (fig. 21). The sea-anemones have no hard parts, but the majority of Anthozoa possess a skeleton, which in many cases is quite external to the body, and is formed of carbonate of lime (fig. 20, 8, 9); in others it is internal and may consist of calcareous spicules, or of an axial rod of horny or calcareous material. The Anthozoa are divided into two Orders, (1) the Zoantharia, (2) the Alcyonaria.

ORDER I. ZOANTHARIA.

In the Zoantharia the tentacles are generally numerous and are never eight in number, as is the case in the Alcyonaria; occasionally there are six only, but frequently a multiple of six, and they usually form several circles around the mouth. The tentacles are nearly always simple (fig. 20, 1). The mesenteries (fig. 21, *a*, *b*, *c*) are usually numerous also, and form several cycles; those belonging to the primary cycle are formed first and reach to the stomodæum; the other cycles (secondary, tertiary, etc.) are successively smaller. The mesenteries are arranged in couples (fig. 21) with the longitudinal muscles of each couple facing one another, except in the case of the couples situated at the grooved ends of the stomodæum, where the muscles are turned away from each other (*d*, *e*). A skeleton is often present and may be calcareous or horny; when calcareous it is never composed of spicules but consists of aragonite fibres.

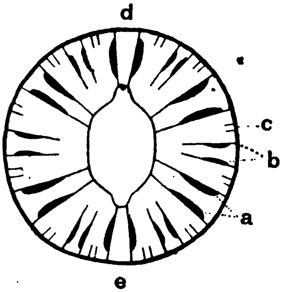

Fig. 21. Diagrammatic section of a Zoantharian polyp passing through the œsophageal tube (stomodæum). *a*, primary mesenteries; *b*, secondary mesenteries; *c*, tertiary mesenteries; *d*, *e*, primary mesenteries at the ends of the compressed stomodæum. The muscles are indicated by the thickenings on the mesenteries.

The Zoantharia comprise, (1) the sea-anemones, which have usually been grouped together as the Actinaria, and are unknown in the fossil state, since they possess no hard parts; (2) the Antipatharia—colonial forms in which the skeleton consists of an internal horny rod secreted by the ectoderm; these also are not found fossil; (3) the Madreporaria, including the well-known stony corals, which are very abundant as fossils.

SUB-ORDER. MADREPORARIA.

The polyp of a Madreporarian coral has essentially the same structure as a common sea-anemone, but the ectoderm of the lower part of the body secretes a skeleton consisting of carbonate of lime (fig. 20, 8, 9). The entire skeleton is spoken of as the *corallum*, and in compound corals the skeleton of each individual is termed a *corallite.* The parts of the skeleton may be solid, or they may be perforated, or formed of a network of rods.

In a typical simple coral (fig. 23) the skeleton has a more or less conical form; the base of the cone, on which the polyp is placed, is usually depressed, and is termed the *calyx.* The wall bounding the corallum is known as the *theca* (fig. 20, 9; fig. 22 *A, d*); sometimes there is, outside this, another calcareous layer, the *epitheca.* The whole space enclosed by the theca is termed the *visceral chamber*; it is divided up by various partitions, the most important of which are the *septa* (fig. 20, 11; fig. 22 *A, b*). These are vertical plates extending from the theca towards the centre, and alternating in position with the mesenteries. The septa are of different sizes, some reaching the centre, others being shorter; they frequently occur in series or cycles, of which three or more may often be

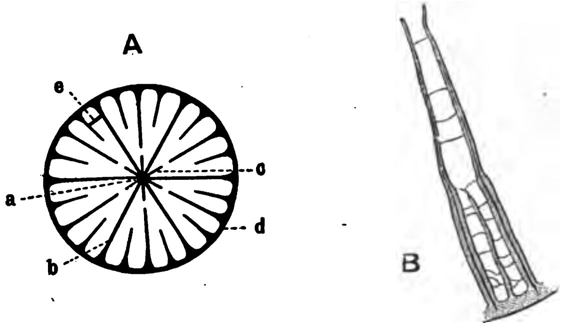

Fig. 22. *A.* **Diagrammatic section (horizontal) of a simple coral. *a*, columella; *b*, primary septa; *c*, pali; *d*, theca; *e*, dissepiments.**

B. **Portion of a horizontal section of *Cyathophyllum murchisoni*, Carboniferous Limestone, showing the middle dark part of the septum; dissepiments near the margin. × 2.**

distinguished, the largest being the *primary* (*b*), the others the *secondary*, *tertiary*, etc. In some corals found in the Palæozoic formations one of the primary septa is much smaller than those formed after it, and consequently appears to lie in a pit or cavity, which is called a *fossula* (fig. 30 *a*). Usually only one septal fossula is present, but sometimes two occur on opposite sides of the coral, and in rare cases three or four are present. It has been suggested that the mesenteries placed in the septal fossulæ were specialised for reproduction. When the septa project upwards above the edge of the theca they are said to be *exsert* (fig. 23). The faces of the septa are sometimes plane, but usually bear ridges, granules, or spines. In some corals the septa are poorly developed, and may be represented by ridges only or by rows of spines. In the centre of the visceral chamber, where the larger septa meet, there is often a vertical rod, which extends from the base of the chamber to the bottom of the calyx; this is the *columella* (figs. 22 *A*, *a*; 28 *c*). Its structure varies considerably; when it is solid and ends in a knob or point in the calyx, it is said to be *styliform*; sometimes the top is porous or *spongy*. When the columella consists of twisted laminæ it is termed *trabeculate*; if formed by the twisting together of processes given off from the inner edges of the septa, it is *false*: in some genera there is no columella. Other vertical partitions, somewhat similar to the septa, are the *pali* (fig. 22 *A*, *c*); these are radiating plates attached to the columella and placed opposite the inner edges of some of the shorter septa,

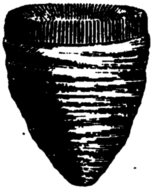

FIG. 23. *Montlivaltia trochoides*, Inferior Oolite, showing exsert septa. × ½.

but not joining them. Bars or rods, known as *synapticulæ,* are often found passing from one septum to another. Similarly, adjacent septa are often connected by plates, which may be horizontal or oblique, straight or curved, and are called *dissepiments* (figs. 22 *A*, *e*; 28 *d*); in some genera they are very abundant near the margin of the visceral chamber and form a spongy or *vesicular* tissue (fig. 27 *d*). Lastly we have the *tabulæ* (fig. 28 *B*, *t*), which are more or less horizontal plates, crossing the septa, and occupying the central part of the visceral chamber or, when well developed, extending quite across it; they are arranged one above another, so that the visceral chamber is divided into horizontal compartments. On the outside of the wall of the coral there are, in some forms, vertical ridges, which may be smooth or spiny; these are known as *costæ,* and usually correspond in position with the septa.

The young coral polyp is a free-swimming animal; when it becomes fixed the first part of the skeleton to appear is a circular plate between the base of the polyp and the surface to which it is attached; on this plate radial ridges—the first traces of the septa—are secreted in folds formed in the base of the polyp between the mesenteries. The theca next appears at the edge of the plate, either by the union of the ends of the septa, or as an independent structure. For some time the polyp extends down to the base of the visceral chamber of the skeleton (fig. 20) and a fold hangs over the outside of the theca (fig. 20, 6, 7); but as the septa, theca, etc., increase in height the lower part of the visceral chamber (in most cases) becomes more or less completely cut off by the development of dissepiments or tabulæ, below which the soft parts do not extend. As growth proceeds more of these partitions are formed, and eventually a large part of the coral ceases to have any direct connexion with the polyp.

Some corals remain simple (*i.e.* consist of a single individual throughout life). Others, which are simple in the young state, afterwards become compound and form colonies, either by giving off buds, or by fission. In budding, new individuals may arise from the part of the polyp which extends outside the theca (fig. 20, 6, 7), in which case a branching coral like *Dendrophyllia* (fig. 24 *A*) is frequently formed; this mode of increase is termed *lateral budding*. In other cases buds arise on the upper surface of the old polyp, and then the young corallites are found inside the calyx of the parent—hence this is known as *calicular* budding (fig. 24 *B*). In *basal budding* (fig. 24 *C*), which is rare in the Madreporaria but common in the Alcyonaria, the buds spring from creeping prolongations or stolons, which are given off from the base of the

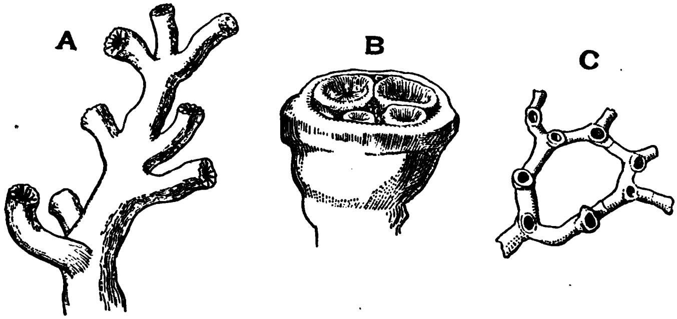

FIG. 24. *A*. *Dendrophyllia nigrescens*, showing corallites which have been produced by lateral budding, Recent. × ½. *B*. *Cyathophyllum truncatum*, showing calicular budding, Wenlock Limestone. Natural size. *C*. *Cladochonus crassus* (seen from above), showing basal budding, Carboniferous Limestone. Natural size.

corallite. Fission, or division into halves, commences by the mouth becoming slightly constricted in the middle, and this goes on until two distinct mouths and two polyps are formed, after which a similar division takes place in the skeleton. When the individual corallites in a compound form are free and diverge from one another, the corallum is termed *dendroid* (fig. 24 *A*): when they are in contact, it is *massive.* If the corallites are not in contact the spaces between the individual corallites are sometimes filled up with calcareous material formed by the cœnosarc, and known as *cœnenchyma.* In many compound corals (*e.g. Acervularia*) the base of the corallum is covered by a thin epithecal plate—the *basal epitheca.*

In dendroid corals (fig. 24 *A*) the polyps on the different corallites are quite separate from one another; but in massive corals, whilst the upper parts of the polyps are more or less separate, the lower parts are united. When cœnenchyma is present the polyps are united by an extension of the part which ordinarily occurs outside the theca, and now forms a sheet called the cœnosarc.

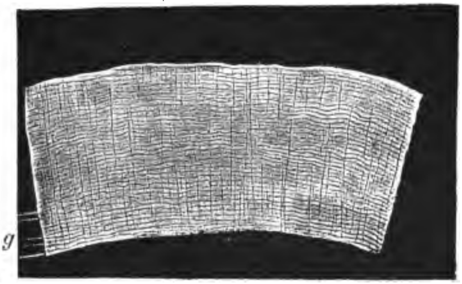

Fig. 25. Section of a dissepiment of *Galaxea*. Magnified. *g*, growth-lamellæ. (From M. M. Ogilvie.)

Microscopic examination of thin sections shows that each part of a coral is formed of thin layers or growth-lamellæ which consist of fine needle-like crystals placed more or less perpendicularly to the surfaces of the lamellæ. In a section of a dissepiment (fig. 25) a series of lines parallel to the surface and other finer lines crossing at right angles are seen—the former mark the growth-lamellæ, the latter the crystalline fibres. In a transverse section of a septum (fig. 26) there is a median dark line or row of dark spots, on each side of which the structure is symmetrical. When the surface of the septum is plane, the lamellæ are straight, or nearly straight, and parallel with the surface, and the fibres are perpendicular; but when the surface is ridged the lamellæ are curved so as to be parallel with the ridges, and the fibres radiate out from

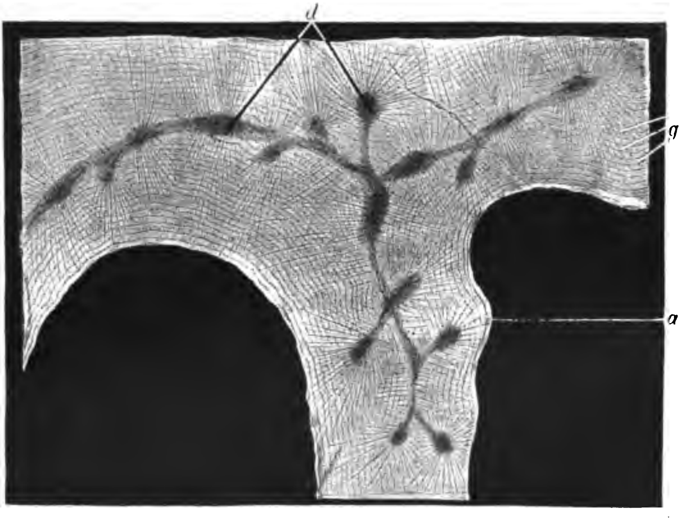

Fig. 26. Transverse section of part of a septum and theca of *Galaxea*. Highly magnified. *d*, dark spots; *g*, growth lamellæ; *a*, granule on septum. (From M. M. Ogilvie.)

the dark median spots toward the curved surface of the ridge (fig. 26). When the septa bear striæ, granules, or spines, in addition to ridges, the folding of the lamellæ and the radiating arrangement of the fibres become more complex; but in all cases the structure is directly related to the form of the surface. The dark lines and spots represent the part of the septum which was first secreted; their dark appearance may be due either to the less regular arrangement of the fibres or to the imperfect calcification of the material of that part. In fossil corals the dark part has often undergone secondary changes which give it a more distinct appearance.

By most authors the Madreporaria have been divided into three sections: (1) the Aporosa, (2) the Perforata, and (3) the Rugosa. It appears, however, that this classification can no longer be maintained. The characters which were regarded as distinctive of these groups are:—

(1) *Aporosa.* Theca and septa solid, the latter generally in multiples of six, with usually six primary septa. Tabulæ rare. Ex. *Turbinolia, Flabellum, Montlivaltia, Parasmilia, Isastræa, Stylina, Thecosmilia, Holocystis.*

(2) *Perforata.* Distinguished from the Aporosa by the septa and theca being perforate. The perforations are sometimes numerous, so that the skeleton appears to consist of a network of rods. Ex. *Litharæa.*

(3) *Rugosa.* Septa and theca solid, tabulæ well developed. The coral is divided into quadrants by four primary septa, and is also usually bilaterally symmetrical owing to the symmetrical arrangement of the septa on either side of two opposite primary septa; and usually one of these primary septa is placed in a fossula, and sometimes the opposite septum also. In rare cases

one or both of the other primary septa are in fossulæ. The Rugosa are found almost entirely in the Palæozoic formations, and the name of the group is taken from the vertical ridges often seen on the wall of the coral. The fourteen genera described on pages 83 to 85 belong to this group.

It is difficult to separate the Aporosa from the Perforata, since some of the former possess a few perforations in the septa, whilst the latter occasionally have nearly compact septa.

The hexameral symmetry which was supposed to distinguish the Aporosa from the Rugosa is now known to be inconstant; frequently other arrangements (tetrameral, pentameral, etc.) of the septa are found. On the other hand the tetrameral symmetry and septal fossulæ are not always present in the Rugosa. Tabulæ are sometimes as well developed in the Aporosa as in the Rugosa. It appears, therefore, that there is no character which will distinguish the Rugosa, as a group, from the Aporosa; but that certain features (tetrameral and bilateral symmetry, tabulæ, fossulæ) are more commonly present in the former than in the latter. Further, it has been shown that certain families of Aporosa, especially those found in the early Mesozoic, approach very closely some of the families of the Rugosa and are probably the descendants of those families; thus, for example, the Astræidæ (Aporosa) are closely related to the Cyathophyllidæ (Rugosa). Consequently, instead of regarding the Rugosa as a circumscribed group which became extinct, or nearly extinct, at the close of the Palæozoic period, we must rather look on the various Rugose families as the ancestral forms from which a number of Aporose families have sprung independently.

Cyathophyllum (figs. 22 *B*, 27). Simple or compound: often massive. Septa numerous, of two sizes, alternating, the longer giving rise to a false columella. Tabulæ rather small, occupying the central part only of the visceral chamber. Dissepiments form an extensive peripheral zone of vesicular tissue. Bala to Carboniferous Limestone. Ex. *C. murchisoni*, *C. regium*, Carboniferous.

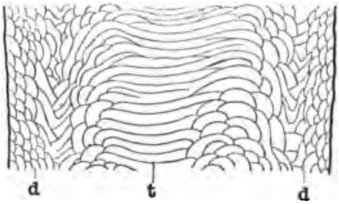

FIG. 27. *Cyathophyllum murchisoni*, Carboniferous Limestone. Portion of a vertical section. *d*, dissepiments; *t*, tabulæ. For horizontal section see fig. 18 *B*.

Acervularia. Compound, massive; corallites with an outer polygonal (frequently hexagonal) theca, and an inner circular wall formed by the thickening of the septa. Septa well developed, reaching the centre. Columella absent. Tabulæ extend across the central part of the visceral chamber. Dissepiments form a peripheral zone of vesicular tissue. Silurian to Devonian. Ex. *A. ananas*, Silurian.

Phillipsastræa (=*Smithia*). Compound, massive. Septa numerous, with oblique ridges: septa of adjacent corallites confluent. Theca thin or indistinct. No columella. Tabulæ and dissepiments well developed. Devonian and Carboniferous. Ex. *P. hennahi* and *P. pengellyi*, Devonian; *P. radiata*, Carboniferous.

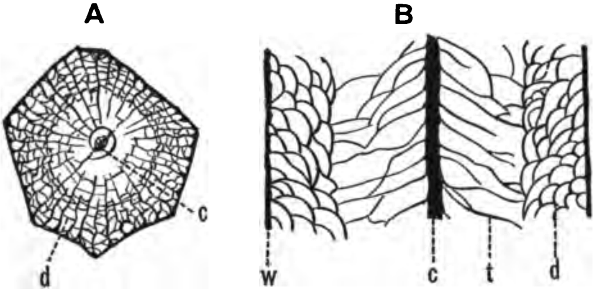

FIG. 28. *Lithostrotion basaltiforme*, Carboniferous Limestone. *A*. Horizontal section of a single corallite, × 2½. *B*. Vertical section, × 5; *c*, columella; *t*, tabulæ; *d*, dissepiments; *w*, theca.

Lithostrotion (fig. 28). Compound, massive and with prismatic corallites, or formed of separated, nearly parallel, cylindrical corallites. Septa well developed, alternately long and short. Columella styliform, laterally compressed. Peripheral zone of dissepiments narrow. Tabulæ wide, occupying the centre of the visceral chamber. Septal fossulæ often well marked. Carboniferous Limestone. Ex. *L. basaltiforme*, *L. junceum*.

Omphyma. Simple, turbinate. Septa numerous, alternately long and short, but extending only a short distance into the visceral chamber, the central part being occupied by tabulæ. The four primary septa are placed in shallow fossulæ. No columella. Peripheral zone of dissepiments narrow. The theca gives off root-like processes. Bala to Lower Ludlow. Ex. *O. subturbinata*, Wenlock Limestone.

Clisiophyllum (fig. 29). Simple, turbinate or subcylindrical. Septa numerous, alternately long and short; a well-marked septal fossula. In the centre of the visceral chamber is a large 'pseudo-columella,' which consists of vertical radiating plates crossed obliquely by vesicular tabulæ; this structure forms a prominent projection at the bottom of the calyx. The pseudo-columella is surrounded by a zone formed of tabulæ, and external to this is a large zone of dissepiments. Carboniferous Limestone. Ex. *C. bipartitum*.

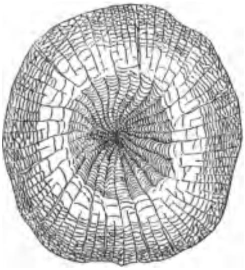

FIG. 29. *Clisiophyllum bipartitum*, Carboniferous Limestone. Horizontal section showing the large central 'pseudo-columella.' Natural size.

Cyclophyllum. Like *Clisiophyllum* but with pseudo-columella surrounded by a distinct wall. Carboniferous Limestone. Ex. *C. fungites*.

Lonsdaleia. Similar to *Clisiophyllum*, but compound, and the septa do not reach the wall of the corallite. Carboniferous Limestone. Ex. *L. duplicata*.

Zaphrentis (fig. 30). Simple, free, bilateral; turbinate, conical or cylindrical, often curved; calyx deep. A well-marked septal fossula in which the septum is small or sometimes absent. Septa numerous. Tabulæ well developed, extending quite across the visceral chamber.

Dissepiments few, never forming a peripheral vesicular zone. Columella absent. Theca thick. Wenlock Limestone to Carboniferous Limestone. Ex. *Z. enniskilleni*, Carboniferous.

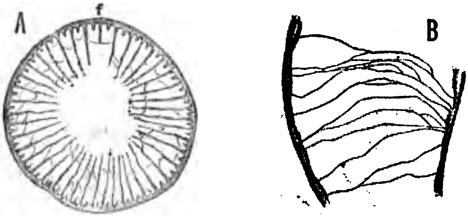

Fig. 30. *Zaphrentis patula*, Carboniferous Limestone. *A*, horizontal section. *B*, vertical section showing tabulæ. *f*, septal fossula. Natural size.

Amplexus. Similar to *Zaphrentis*, but generally cylindrical, and with very short septa. Ex. *A. coralloides*, Carboniferous.

Streptelasma. Simple, conical or turbinate, with a thick wall. A septal fossula present, but sometimes obscure. Columella large, trabeculate. Tabulæ irregular, usually poorly developed. Dissepiments few. Ordovician to Devonian. Ex. *S. corniculum*, Ordovician.

Cystiphyllum. Simple, conical. Septa and tabulæ absent or rudimentary; visceral chamber filled with vesicular tissue, the outer part consisting of dissepiments, the central part representing tabulæ. Columella absent. Calyx sometimes deep, sometimes shallow, often with ridges representing septa. Silurian and Devonian. Ex. *C. vesiculosum*, Devonian.

Calceola (fig. 31). Simple, conical or slipper-shaped, one side is flat, the opposite convex; calyx very deep and closed by a semilunar operculum, which has on its inner surface a strongly marked median ridge and several less prominent lateral ridges; septa indicated by striæ. An epitheca is present. Middle Devonian. Ex. *C. sandalina*.

Goniophyllum. Similar to *Calceola*, but quadrangular; operculum consists of four pieces forming a pyramid over calyx.

Silurian. Ex. *G. fletcheri*, Wenlock Limestone. An operculum also occurs in *Rhizophyllum*, Silurian.

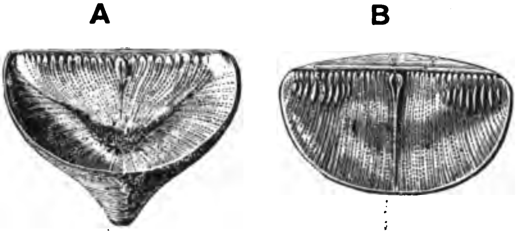

FIG. 31. *Calceola sandalina*, from the Middle Devonian; *A*, showing interior of calyx; *B*, inside of operculum of the same. Natural size.

Turbinolia. Simple, conical, free; calyx circular, with projecting columella. Septa exsert. Costæ lamellar, projecting, with pits in the grooves between them. No dissepiments or tabulæ. Eocene and Oligocene (? Recent). Ex. *T. humilis*, Barton Beds.

Flabellum. Simple, compressed, fan-shaped, free or fixed by rootlets. Calyx narrow, deep; septa numerous. Columella trabeculate. Costæ smooth or spiny. Eocene to present day. Ex. *F. woodi*, Coralline Crag.

Montlivaltia (fig. 23). Simple, fixed or free; turbinate, cylindrical, conical, or discoidal. Epitheca well developed, theca thin. Columella absent. Septa numerous, strong, often exsert, the upper edges dentate. Dissepiments abundant. Trias to Recent; in England, Lias to Corallian. Ex. *M. trochoides*, Inferior and Great Oolites.

Parasmilia. Simple, fixed, turbinate or elongated. Calyx circular. Columella spongy. Septa well developed, exsert, granular on the sides. Wall with costæ. Cretaceous to present day; in England, Chalk. Ex. *P. centralis*, Chalk.

Isastræa. Compound, massive; calyces polygonal. Walls of the corallites fused along their entire length. Columella rudimentary or absent. Septa thin and close together. Dissepiments abundant. Trias to Eocene; in England, Lias to Upper Greensand. Ex. *I. explanata*, Corallian.

Stylina. Compound, usually massive; calyces circular, projecting, usually separated. Columella small, styliform. Septa exsert. Dissepiments abundant. Corallites united by costæ. Basal epitheca with folds. Trias to Cretaceous; in England, Inferior Oolite to Corallian. Ex. *S. tubulifera*, Corallian.

Thecosmilia. Compound, dendroid or rarely almost massive. Multiplication by fission. Margins of calyces irregular. Columella rudimentary or absent. Septa strong, upper edges dentate, more or less exsert. Dissepiments abundant. Epitheca thick and folded, but often not preserved. Trias to Tertiary; in England, Lias to Kimeridgian. Ex. *T. annularis*, Corallian and Kimeridgian.

Holocystis. Compound, massive, convex; calyces polygonal. Columella very small. Corallites united by their walls or by costæ. The four primary septa are much better developed than the others. Tabulæ well developed. Lower Greensand. Ex. *H. elegans.*

Thamnastræa. Compound, massive; convex or laminar. Walls of the corallites indistinct. Calyces shallow. Septa of adjoining corallites confluent; faces of septa with granulations. Columella small, trabeculate. Dissepiments present, synapticulæ numerous. Usually a basal epitheca. Trias to Miocene; in England, Lias to Upper Greensand. Ex. *T. arachnoides*, Corallian.

Micrabacia. Simple, free, discoidal, base concave. Columella false. Septa numerous, with their outer edges perpendicular. Synapticulæ present. Theca on the base only, thin; costæ granular. Upper Cretaceous. Ex. *M. coronula.*

Litharæa. Compound, massive. Calyces more or less polygonal. Septa well developed, the faces spiny, the upper edges dentate. Walls of the corallites reticulate. Columella formed by the ends of the septa. Eocene to Miocene. Ex. *L. websteri*, Bracklesham Beds.

ORDER II. ALCYONARIA.

The Alcyonaria are nearly all colonial organisms; the polyps possess eight mesenteries and eight tentacles, the latter being provided with pinnules (fig. 32, 4). In the stomodæum there is only one groove with cilia, and the longitudinal muscles on the mesenteries are all directed toward the groove (fig. 33, 6). All the mesenteries reach the stomodæum (1). The nature of the skeleton varies considerably; in *Alcyonium* it consists of isolated spicules

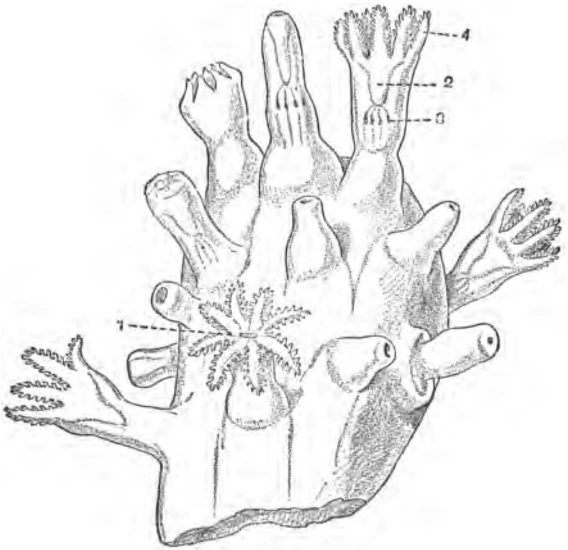

Fig. 32. **Part of a colony of *Alcyonium digitatum*, showing thirteen polyps in various stages of retraction and expansion. (From Shipley and MacBride.) 1, mouth; 2, œsophagus; 3, mesenteries; 4, tentacles. × 8.**

of carbonate of lime embedded in the common gelatinous base in which the polyps are placed. In some cases it has the form of an axial rod surrounded by the soft parts; this rod may consist of horny material (*e.g. Gorgonia*) or of carbonate of lime (*e.g. Corallium*, the red coral), or it may be formed of alternating segments of horny and of calcareous material as in *Isis*. In the 'organ-pipe coral' (*Tubipora musica*, fig. 34) the skeleton consists of numerous parallel tubes or corallites (*a*) which are not in contact but are held together by horizontal calcareous plates or 'platforms' (*b*). The walls of the corallites, although apparently quite compact, are really composed of spicules which have serrated edges and are firmly fitted together. A single polyp lives at the summit of each corallite; spicules occur in the middle gelatinous layer of the polyp, and in the lower part become interlocked to form the solid wall of the

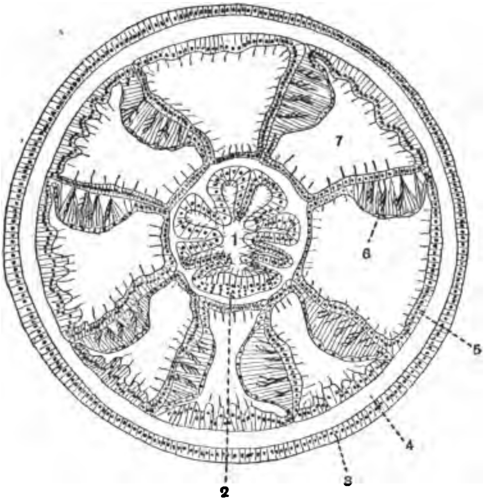

FIG. 33. Transverse section through a polyp of *Alcyonium digitatum*, in the region of the stomodæum. × about 120. 1, cavity of stomodæum or œsophagus; 2, groove with cilia (siphonoglyph); 3, ectoderm; 4, gelatinous layer; 5, endoderm; 6, muscles of mesenteries; 7, cavity between mesenteries. (From Hickson.)

corallite. The interior of each corallite is divided up by tabulæ which are often funnel-shaped (fig. 34 *c*).

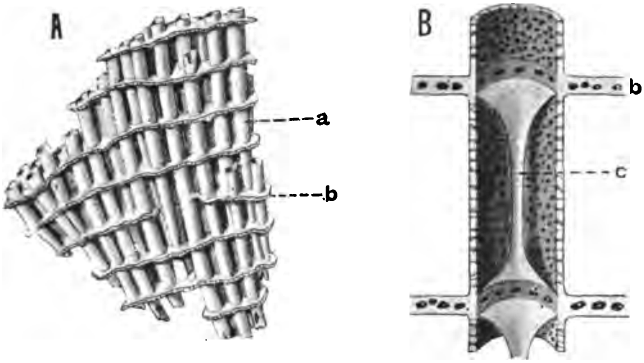

FIG. 34. *Tubipora musica*, Recent. *A*, part of a colony, natural size. *B*, diagrammatic vertical section of one corallite (enlarged) showing canals in the wall and platform. *a*, corallite; *b*, platform; *c*, tabula.

In some of the Alcyonaria, as for example *Pennatula*, there are in addition to the ordinary polyps (or *autozooids*) others of a more rudimentary character, known as *siphonozooids*, in which tentacles are absent.

The blue coral (*Heliopora*) differs from all other living Alcyonaria in that the skeleton consists of calcareous fibres instead of spicules, and in this respect resembles the Madreporaria. *Heliopora* has the form of branched or lobed masses, and is composed of tubes of two sizes; the larger tubes or corallites are circular and possess usually fifteen spine-like projections at their summits with ridges below; these are called pseudosepta, since they are not related to the number of mesenteries and do not correspond with true septa. The smaller tubes form a cœnenchyma between the corallites, and are more irregular in form. Both corallites and cœnenchymal tubes are divided by horizontal plates or tabulæ. The soft parts form a thin sheet over the surface of the skeleton; polyps (fig. 35, *ab*) are placed in the corallites and give off branching tubes (*d*) which cover the cœnenchyma and send blind prolongations or cæca (*e*) into the tubes of the cœnenchyma. The cæca were formerly regarded as siphonozooids.

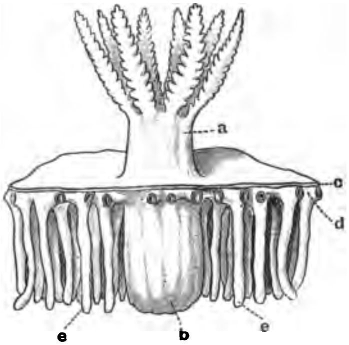

FIG. 35. *Heliopora cœrulea.* A single polyp and the adjacent soft parts. *a*, the projecting part of the polyp with eight pinnate tentacles; *b*, lower part of the polyp; *c*, ectoderm; *d*, sheet of canals; *e*, cæca. (From Bourne.)

Alcyonaria are rare as fossils, unless the Palæozoic genera, described below, be included in that group[1]; but the systematic position of these Palæozoic forms cannot yet be regarded as definitely established. Some of them present considerable resemblance to living Alcyonaria; for example, *Syringopora* is similar to *Tubipora,* and *Heliolites* to *Heliopora*: on account of this, many authors maintain that these fossil forms belong to the Alcyonaria, but this relationship is denied by other writers who point out the similarity between *Favosites* and the living Madreporarian *Alveopora*; if it could be shown that these two forms are related, then it would follow that *Favosites* and other allied fossil genera (including *Syringopora*) must be placed in the Madreporaria.

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[1] The Monticuliporoids, which range from the Ordovician to the Permian, are placed by some authors in the Alcyonaria, but by others in the Polyzoa.

Syringopora. Compound; corallites tubular, for the most part not in contact, more or less parallel. The visceral chambers of the different corallites are placed in communication by means of horizontal connecting tubes. Septa feebly developed, generally represented by rows of spines. Tabulæ numerous, funnel-shaped. Budding basal. Llandovery to Carboniferous Limestone. Ex. *S. reticulata*, Carboniferous.

Syringopora agrees with *Tubipora* (fig. 34) in consisting of parallel, cylindrical corallites, which have funnel-shaped tabulæ, and in its basal-budding; it differs from *Tubipora* in having much thicker walls which are not composed of spicules, and are not perforated by minute canals; also in having the tabulæ much less regular in form and position, and in having septa represented by spines. The platforms of *Tubipora* (which are traversed by canals opening into the corallites) are represented by the connecting tubes of *Syringopora*; in one species of *Syringopora* (*S. tabulata*) the resemblance is particularly close, since the connecting tubes are given off from the corallites at definite levels in a radiating manner.

Favosites. Compound, massive, sometimes branched. Corallites long and polygonal; the walls are in contact but not fused, and are perforated by pores ('mural pores') arranged in rows along each face. Septa absent or represented by rows of spines. Tabulæ numerous, regular, generally extending quite across the visceral chamber. Basal epitheca present. Bala to Carboniferous Limestone. Ex. *F. gothlandica*, Silurian.

Favosites is related to *Syringopora*, but the corallites are in contact, and the connecting tubes are consequently absent, though probably represented by the mural pores. The living Madreporarian *Alveopora* agrees in general structure with *Favosites*, but its walls are less compact, and its basal epitheca is quite small. Some corals (e.g. *Koninckia*, *Ubaghsia*) which resemble *Favosites* are found in the Upper Cretaceous, and are regarded by some writers as links between *Favosites* and *Alveopora*.

Pachypora. Similar to *Favosites*, but the walls of the corallites are greatly thickened, especially near the surface of the coral, by a secondary deposit of carbonate of lime. Silurian to Carboniferous. Ex. *P. cervicornis*, Devonian.

Alveolites. Allied to *Favosites*. Massive, encrusting, or branching. Corallites laterally compressed, with thin walls and large mural pores. Silurian and Devonian. Ex. *A. labechei*, Silurian.

Pleurodictyum. Compound, discoidal, attached by part of the base, upper surface slightly convex. Corallites diverge from the centre of the base; walls thick, with irregular pores. Septa rudimentary. Tabulæ not numerous, more or less united. A basal epitheca. Silurian and Devonian. Ex. *P. problematicum*, Devonian.

Michelinia. Similar to *Pleurodictyum*, but the tabulæ are more numerous and form a vesicular tissue, and root-like processes are usually given off from the epitheca on the base of the coral. Devonian and Carboniferous. Ex. *M. favosa*, Carboniferous.

Heliolites (fig. 36). Corallum compound, massive or branching, formed of tubes of two sizes; the larger circular ones are the corallites, between which come the smaller polygonal tubes forming the cœnenchyma. Tabulæ occur in both, and in the corallites there are lamellar septa also, which are usually twelve in number. Columella sometimes found in the corallites. Bala to Devonian. Ex. *H. porosus*, Devonian.

In general structure *Heliopora* is similar to *Heliolites*, but is more branching, whilst *Heliolites* forms rounded or encrusting masses; further, the smaller tubes which form the cœnenchyma branch dichotomously in *Heliolites*, but in *Heliopora* new tubes are introduced between the older ones. By many writers these two genera are considered to be closely allied, but the relationship is denied by others, who state that important differences are found in the structure of the corallite walls and septa. According to Lindström and others, the corallites of *Heliolites* possess a distinct and independent wall (theca) and also have well-developed septa, whilst in *Heliopora* the corallites are simply bounded by the walls of the cœnenchymal tubes, and possess only ridges instead of septa except at the openings of the corallites. Bourne, on the other hand, considers that the corallites of *Heliolites* possess no independent wall, and agree in this respect with *Heliopora*. There is a great interval of time between the last appearance of *Heliolites* and first appearance of *Heliopora*; the former and its allies are not known in rocks of later age than the Devonian, while the latter has been recorded in rocks of Cretaceous and later date only. In the Cretaceous, however, *Polytremacis* is found, and is regarded by Gregory as a connecting link between *Heliolites* and *Heliopora*.

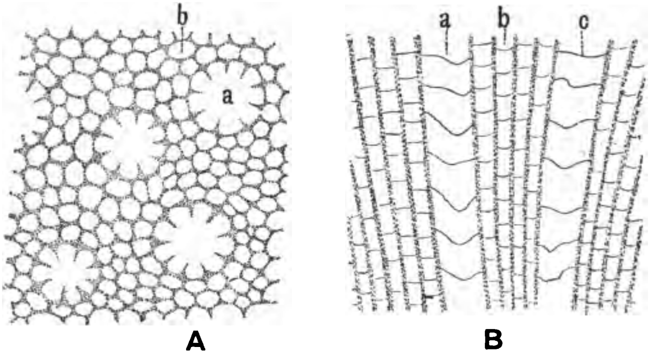

FIG. 36. *Heliolites porosus*, Devonian. *A*. Horizontal section. *B*. Vertical section. *a*, corallites; *b*, tubes forming the cœnenchyma; *c*, tabulæ. Enlarged.

Plasmopora. Allied to *Heliolites*. Usually discoidal or hemispherical. Walls of smaller tubes incomplete or absent, and their tabulæ forming a vesicular tissue. Septa in corallites lamellar, and prolonged outside each calyx, so as to enclose large spaces of uniform size. Basal epitheca with concentric ridges. Ordovician to Devonian. Ex. *P. petaliformis*, Silurian.

Propora. Allied to *Plasmopora*. Edges of calyces projecting; septa represented by spines, and not prolonged outside calyx so as to enclose large spaces. Ordovician to Silurian. Ex. *P. tubulata*, Wenlock Limestone.

Halysites. Compound; corallites long and tubular, arranged in a single row and united at their sides so as to form laminæ, which intersect; in some species the corallites are of two sizes—the smaller perhaps represent the cœnenchymal tubes of *Heliolites*. Epitheca thick. Septa absent or represented by spines. Tabulæ well developed, horizontal or concave. Llandeilo Beds to Wenlock Limestone. Ex. *H. catenularia*, Wenlock Limestone.

Chætetes. Massive, often laminar, consisting of slender, tube-like polygonal corallites; walls thin, without perforations. Tabulæ few, widely separated. Chiefly Carboniferous. Ex. *C. radians*. The systematic position of *Chætetes* is uncertain; by some authors it has been referred to the Polyzoa.

Distribution of the Anthozoa.

From the point of view of their distribution at the present day, the Madreporaria may be divided into two groups, the solitary and the reef-building.

The solitary corals (*i.e.* the corals which do not form reefs) are found in almost all latitudes, but live mainly in rather deep water, the larger number occurring between depths of 50 and 1000 fathoms; some few (*e.g. Caryophyllia*) live in quite shallow water, whilst others inhabit the depths between 1000 and 2900 fathoms. The species of solitary corals have a wide distribution, being apparently but little affected by conditions of temperature and depth. It might therefore be expected that they would also have a long range in time; this however is not the case, for existing species extend but a short way back into the geological record, and not a single living form is found fossil in the English Cainozoic formations; about a third of the living genera, however, are represented in Cainozoic rocks, and a few (*e.g. Caryophyllia, Parasmilia, Trochocyathus*) occur in Mesozoic formations, but none range into the Palæozoic.

The distribution of the reef-building corals, unlike that of the solitary forms, is limited by both depth and temperature. Thus they are found only in shallow water, not usually extending lower than 20 or 30 fathoms, and only where the temperature of the ocean is not less than 65° F.; they flourish only in water warmer than this. Like the solitary corals, the reef-building genera of the present day have but a very limited geological range, only a very few extending back so far as the Mesozoic period.

Corals, with possibly one or two exceptions, can only exist in salt water; but *Madrepora cribripora* is said to inhabit nearly fresh water. Clear water is likewise generally necessary, but one species, *Porites limosa,* thrives in muddy situations. In geological times, and especially in the Palæozoic and Mesozoic periods, the reef-building corals had a much wider geographical range than they have at the present day, and their remains occur abundantly in various formations in both temperate and polar regions; but in the course of the later Cainozoic period the range of the reef-builders became more and more restricted until the present limits were reached.

The Alcyonaria occur in all parts of the world, and are found at all depths from the shore-line down to 2,300 fathoms, but they are most abundant at depths of less than 100 fathoms; beyond this limit the number of species gradually diminishes as the depth of the water increases.

The Palæozoic families which have been referred to the Alcyonaria are almost entirely unrepresented in later formations. Very few of the modern Alcyonarian families occur fossil, but the Pennatulidæ are represented in the

Trias by *Prographularia,* in the Cretaceous by *Pavonaria,* and in the Cainozoic by *Graphularia.* The red coral, *Corallium,* is found in the Cretaceous and Cainozoic (perhaps also in the Jurassic); forms allied to *Gorgonia* occur in the Cretaceous and Tertiary rocks; *Isis* is found in the Cainozoic, and perhaps also in Cretaceous formations. Spicules, similar to those of *Alcyonium,* have been detected in the Upper Cretaceous. *Heliopora* is first recorded from the Cretaceous. The organ-pipe coral, *Tubipora,* has not been found fossil.

Fossil corals are comparatively rare in argillaceous and arenaceous beds but usually abundant in calcareous rocks, many limestone rocks being formed almost entirely of coral remains. This is indeed what might be expected, since existing forms can, as a general rule, live only in clear water.

The chief features in the geological distribution of the Anthozoa are given in the following table.

Cambrian. A few corals have been recorded from this system in North America and the south of Europe (Sardinia and Spain) *Archæocyathus, Coscinocyathus, Ethmophyllum.*

Ordovician. In North America corals (especially *Streptelasma*) are common in this system, but in England only a few forms have been found, the most important being *Favosites, Heliolites, Halysites.*

Silurian. Corals are very abundant, especially in the Wenlock Limestone. *Cyathophyllum, Acervularia, Omphyma, Lindstrœmia, Goniophyllum, Syringopora, Favosites, Heliolites, Plasmopora, Halysites.*

Devonian. *Cyathophyllum, Acervularia, Phillipsastræa* (=*Smithia*), *Cystiphyllum, Calceola, Favosites, Pachypora, Pleurodictyum, Heliolites.*

Carboniferous. *Cyathophyllum, Lithostrotion, Clisiophyllum, Cyclophyllum, Lonsdaleia, Zaphrentis, Amplexus, Michelinia, Syringopora.*

Permian. Only a very few forms have been found.

Trias. Corals are absent in England, but abundant in the Alpine Trias; most of the Palæozoic forms have become extinct and we find in place of them *Rhabdophyllia*, *Cladophyllia*, *Montlivaltia*, *Thecosmilia*, *Isastræa*, *Phyllocœnia*, *Astrocœnia*, *Stylina*, *Omphalophyllia*.

Jurassic. *Montlivaltia*, *Isastræa*, *Thamnastræa* and *Thecosmilia* are found in the Lias but are not common; in the Oolites they become very abundant and several other genera also occur, *e.g.* *Stylina*, *Cyathophora*, *Cladophyllia*, *Calamophyllia*, *Anabacia*.

Cretaceous. Corals are not abundant in England; the chief forms are *Parasmilia*, *Trochocyathus*, *Micrabacia*, *Holocystis*. In some parts of Europe, especially in the Gosau beds (of Chalk age) of the Austrian Alps, corals are very numerous, and include *Cyclolites*, *Astrocœnia*, *Thamnastræa*, etc.

Cainozoic. Corals are rare in English Cainozoic formations: *Turbinolia*, *Dendrophyllia*, *Oculina* and *Litharæa* occur in the Eocene; *Madrepora* in the Oligocene; *Flabellum* in the Pliocene. In the middle and south of Europe, corals are found abundantly in various Cainozoic deposits.

PHYLUM ECHINODERMA.

Sub-Phyla.	*Classes.*
1. Eleutherozoa	1. Asteroidea.
	2. Ophiuroidea.
	3. Echinoidea.
	4. Holothuroidea.
2. Pelmatozoa	1. Crinoidea.
	2. Cystidea.
	3. Blastoidea.
	4. Edrioasteroïdea.

THE animals included in this division are all marine; they comprise the starfishes, brittle-stars, sea-urchins, sea-lilies, sea-cucumbers, and the extinct blastoids and cystideans. The body is very often radially symmetrical, the symmetry being generally pentamerous. But in many cases there is also a more or less well-marked bilateral arrangement of parts. The echinoderms are never compound animals. In the majority of cases the alimentary cavity terminates in an anus. A body-cavity or cœlom is present and surrounds the alimentary canal. The water-vascular system is one of the distinguishing features of the group; it consists of a set of vessels containing a watery fluid and generally placed in communication with the sea-water by means of a canal; one vessel forms a ring round the œsophagus from which radiating trunks are given off. The water-vascular system functions generally in locomotion, and also in respiration. A nervous system is present and has a distribution similar to that of the water-vascular system. Reproduction is mainly sexual; as a rule the sexes are separate, but they do not differ externally.

In all the echinoderms there is a dermal skeleton. This is calcareous and consists sometimes of isolated pieces, but more usually of rods or plates, forming a complete shell or test, which may be either flexible or rigid; spines and other processes are often attached to the plates. When examined microscopically each part of the skeleton is found to be formed of a network of calcareous rods (fig. 37). The details of the structure vary in different forms, depending on the size and shape of the spaces between the rods. In the spines of sea-urchins the network of rods has usually a radial arrangement, with polygonal or rectangular spaces (fig. 37 *A*), except at the centre, where the structure is more irregular. Another characteristic feature of the skeleton is that each component part shows the optical characters of a crystal of calcite, and differs only from an ordinary crystal in not having crystal contours and in the possession of the netted

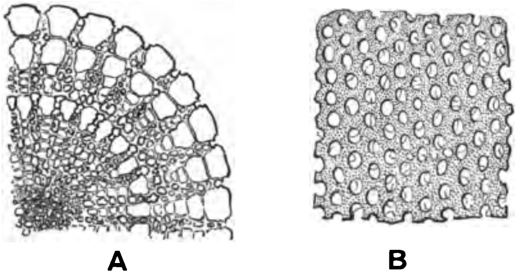

Fig. 37. *A*. Portion of transverse section of a spine of a sea-urchin, *Echinometra*, Recent. Magnified. *B*. Section of interambulacral plate of recent *Cidaris* cut parallel to the surface. Magnified.

structure. In a plate the principal crystallographic axis is at right angles to the surface, in a spine it is parallel with the length. In fossil specimens the spaces in the network of rods usually become filled with calcite, which is deposited in crystalline continuity with that forming the plate or spine. In such cases the characteristic cleavage of calcite becomes well marked, so that when the plate or spine is broken, the fracture passes along the cleavage planes, instead of being irregular as in the recent forms. By the infiltration of calcite and the development of cleavage, the organic structure in fossil echinoderms is sometimes more or less completely destroyed.

The Echinoderma are divided into eight classes:—(1) Asteroidea; (2) Ophiuroidea; (3) Echinoidea; (4) Holothuroidea; (5) Crinoidea; (6) Cystidea; (7) Blastoidea; (8) Edrioasteroidea. The first four classes include the free forms and are grouped together as the *Eleutherozoa*; the remaining four classes are known as the *Pelmatozoa*, the members of which are characterised by being attached, by means of a stem, to the sea-floor or other foreign object during some part of their existence, and by having the mouth directed upwards.

I. ELEUTHEROZOA.

CLASS I. ASTEROIDEA.

The Asteroidea or starfishes have a flexible body which may be pentagonal in outline, but is usually more or less star-shaped, consisting of a central part, known as the *disc*, and of five *arms* or *rays*. In a few forms there are more than five arms, *e.g.* *Solaster papposus* has thirteen.

The mouth is at the centre of the disc on the under surface, and along the under surface of the arms are rows of tubular processes, the *tube-feet*, which are connected with the radial water-vessel. This surface of the body is called the *oral*, *ambulacral*, *actinal* or *ventral* surface. The upper surface is *aboral*, *anti-ambulacral*, *abactinal* or *dorsal*; on it occur the anus and madreporic plate. The anus is situated near the centre of the disc, but in some forms (*Astropecten*) is absent. The *madreporite* or *madreporic plate* is a porous plate placed between two of the rays on the disc; sometimes more than one is present.

On the ventral surface, extending from the mouth to the tip of each arm, is a deep groove, the *ambulacral groove*; this is formed by two rows of plates known as the *ambulacral ossicles* (fig. 38, *a*), which are in contact dorsally; the ossicles on one side of the groove are movably articulated with those opposite. Along each side of the ambulacral groove there is a row of pores, each pore being between two ossicles; generally the pores are arranged in a straight line, but in some forms they are zigzag, being alternately near to, and distant from, the middle of the ambulacral groove. External to the rows of ambulacral ossicles there is, on each side of the groove, another row of plates, the *ad-ambulacral plates* (*b*). At the sides of the arms there are in many cases two rows of *marginal plates* (*c*, *d*)—the *superior-* and *inferior-marginals*. In some forms marginal plates are small or absent. The dorsal surface of the skeleton is formed of a meshwork of calcareous rods with leathery skin in the inter-spaces, but

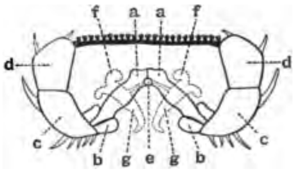

Fig. 38. Section of the arm of a star-fish (*Astropecten*). *a*, ambulacral ossicles; *b*, ad-ambulacral plates; *c*, inferior-marginal plates with spines; *d*, superior-marginals; *e*, radial water vessel; *f*, ampulla; *g*, tube-feet. Enlarged.

in a few forms distinct plates are present on the disc, there being sometimes a central plate with others arranged in circles around it. Short spines are often abundant. *Pedicellariæ* are also of frequent occurrence, especially on the dorsal surface; they are modified spines consisting typically of two movable blades which are often borne on a stalk, and probably serve to remove foreign bodies from the surface of the animal. Projecting into the mouth at the angles formed by the ambulacral grooves are five pairs of plates, which give the mouth a star-shaped form. The mouth leads into a short œsophagus which opens into the globular stomach; above the stomach is the pentagonal pyloric sac, from the angles of which branches, which soon divide into two, are given off, and extend down the arms near the aboral surface. From the pyloric sac a short narrow intestine leads to the anus at the centre of the dorsal surface. The water-vascular system consists of a vessel forming a ring round the œsophagus (fig. 39, *a*), from which ring a branch (*b*) is given off to each arm and is placed in the ambulacral groove outside the skeleton. Each of these radial vessels gives off two rows of processes on opposite sides, which pass through the pores between the ambulacral ossicles into vesicles situated dorsally to the ossicles and known as the *ampullæ* (*g*), and also into

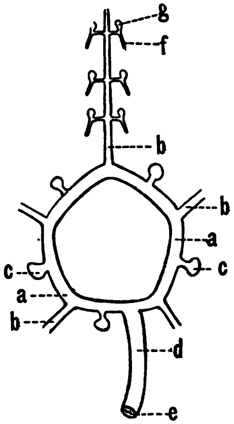

FIG. 39. Diagram of the water-vascular system of a star-fish. *a*, circular vessel round the mouth; *b*, radial vessels; *c*, Polian vesicles; *d*, stone-canal; *e*, madreporic plate; *f*, tube-feet (only a few shown); *g*, ampulla.

the tubular processes known as the *tube-feet* (*f*), which project along the ventral surface of the arm and are provided at their extremities with sucking-discs. The discs become attached to foreign bodies, and by means of the contraction of the tube-feet the animal moves. The water-vascular system is placed in communication with the exterior by a canal (fig. 39, *d*) passing from the circular vessel to the dorsal surface of the disc and ending in the madreporic plate. This is known as the *stone-canal* on account of the deposit of carbonate of lime in its walls. On the dorsal surface, and sometimes upon other parts of the body also, there are tube-like projections of the skin, which form simple respiratory organs known as *dermal branchiæ.*

The distribution of the main part of the nervous system is similar to that of the water-vascular system. It consists of a ring round the mouth and of a branch which extends down the ambulacral groove of each arm; there is also a layer of fine nerve-fibres under the ectoderm. At the tip of each arm is an eye-spot. The genital glands occur in pairs at the base of each arm and they open to the exterior between the rays on the dorsal surface, but in some few cases the openings are on the ventral surface.

Palæaster. Body pentagonal. Arms thick, convex, short or of moderate length; dorsal surface formed of rows of small ossicles provided with spines. Ambulacral ossicles alternating on either side. There is a row of ad-ambulacral plates and also a row of large marginal plates. Madreporic plate small. Bala Beds to Carboniferous. Ex. *P. eucharis,* Devonian.

Palæasterina. Disc large, pentagonal. Arms short, but distinctly marked off from the disc; ambulacral ossicles alternating; marginal plates smaller than ad-ambulacrals and with small spines.

Ad-ambulacrals boot-shaped. Disc with rounded and isolated plates; on the dorsal surface a central plate is surrounded by a circle of five others, and four rows of plates occur on the dorsal surface of each arm. Ordovician and Silurian. Ex. *P. primæva*, Ludlow.

Calliderma. Body flattened, pentagonal-stellate, with the rays moderately long. Marginal plates large, forming a broad border to the disc, covered with granules. Dorsal surface of disc with small plates arranged regularly. Cretaceous to present day. Ex. *C. mosaicum*, Chalk.

Metopaster. Body flattened, pentagonal in outline, the rays only slightly produced. Marginal plates thick, covered with punctations and surrounded by a depressed border. Superior-marginal plates few in number, forming a broad border to the disc; the terminal pair of plates the largest. Dorsal surface covered with small polygonal (usually hexagonal) plates. Inferior-marginal plates more numerous than the superior-marginals. Plates on the ventral surface small, polygonal. Cretaceous. Ex. *M. parkinsoni*, Upper Chalk.

Mitraster. Similar to *Metopaster*, but rounded (or slightly pentagonal) in form, with superior-marginal plates few and all of equal size. Chalk. Ex. *M. hunteri.*

Palæocoma. Arms rather short. Ambulacral grooves narrow and shallow; ambulacral ossicles numerous and alternating on either side. Ad-ambulacral plates large; the adjoining row of plates with numerous long spines. Disc with small plates. Silurian. Ex. *P. marstoni*, Ludlow.

Distribution of the Asteroidea.

The Asteroidea have a wide distribution in the ocean at the present day; they are most abundant at moderate depths, but also occur in abyssal regions.

The fossil forms do not differ greatly from the modern ones, but many of those found in the Palæozoic formations have the ambulacral ossicles alternating on either side of the ambulacral groove. The earliest star-fishes are found in the Tremadoc Beds. The genus *Palæaster* appears in the Bala Beds. The group is more abundant in the Silurian, where *Palæaster*, *Palæasterina*, *Urasterella*, *Lepidaster*, and *Palæocoma* occur. *Palæaster*, *Aspidosoma* and others are found in the Devonian. The Jurassic forms have been referred to the genera *Solaster*, *Astropecten*, and *Plumaster*. *Calliderma*, *Metopaster*, *Pentagonaster*, and *Mitraster* occur in the Upper Cretaceous. In the Cainozoic rocks star-fishes are rare.

CLASS II. OPHIUROIDEA.

In the Ophiuroids or brittle-stars, the body consists of a disc and arms. The arms are generally five in number, usually simple, but in some cases branched; they are much smaller than in the star-fishes and are merely appendages of the disc and not prolongations. Usually they are long, cylindrical, and very flexible, serving for locomotion by means of movements which take place chiefly in a horizontal direction. Unlike the arms of the star-fish they do not contain any prolongations of the alimentary canal, and the ambulacral groove is not open to the exterior. The arrangement of the nervous and the water-vascular systems is similar to that found in the Asteroidea, but the tube-feet are not provided with sucking-discs and there are no ampullæ. The madreporic plate is on the ventral surface. There is no anus, and pedicellariæ are nearly always absent.

Generally there is a well-developed skeleton. In a typical case the following parts are found. Encasing the arms, there are four rows of plates (fig. 40), one dorsal, one ventral, and two lateral. The lateral plates are provided with rows of spines. Between the lateral and the ventral plates are apertures for the passage of the tube-feet. The greater part of the space enclosed by the four rows of plates is filled up by a longitudinal row of ossicles (*d*); each ossicle consists of two parts which are nearly always fused together along the median vertical line. Each ossicle in the row articulates with the preceding and succeeding one, so that the arm is flexible. On the ventral surface of the row there is a groove (*e*) in which the water-vascular vessel and the nerve cord are placed; this corresponds to the ambulacral groove of the star-fish, and the plates above represent the ambulacral ossicles.

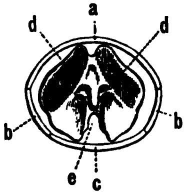

FIG. 40. Section of the arm of an Ophiuroid (*Ophioglypha*). *a*, dorsal plate; *b*, lateral plate; *c*, ventral plate; *d*, ambulacral ossicles fused along the median vertical line; *e*, ambulacral groove. Enlarged.

The disc is usually round or pentagonal. On its ventral surface (fig. 41 *A*) the arms are prolonged so as to reach the mouth. The last pair of ambulacral ossicles,—those next the mouth, instead of being fused like the others, remain free, and each ossicle unites with that of the adjoining arm. The parts of the disc between the arms are known as the *interbrachial areas*; these are covered mainly with scaly plates and granules, but in each of the areas there is one large plate, the *buccal plate* (*b*), and other smaller plates, projecting into the mouth, giving it a stellate form. One of the buccal plates serves as the madreporic plate. The genital openings (*g*) also occur on the ventral surface of the disc; they are in the form of slits in the interbrachial areas, usually two in each, situated near the bases of the arms; occasionally there are four.

The dorsal surface of the disc (fig. 41 *B*) is, in most cases, covered with numerous small plates; but usually there is at the bases of the arms on each side a large plate, the *radial plate* (*r*); there may also be a large plate at the centre of the disc surrounded by one or more circles of five plates. On this surface the arms end abruptly at the margin of the disc.

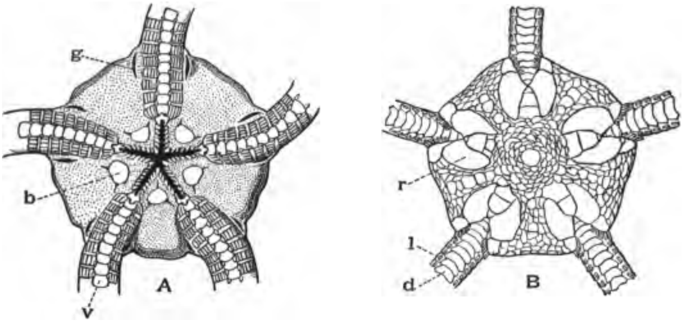

FIG. 41. *A*. *Ophiura*, Recent. Ventral surface of disc and part of the arms. *b*, buccal plates; *g*, genital slits; *v*, ventral plates of arms. *B*. *Ophioglypha*, Recent. Dorsal surface. *r*, radial plates; *l*, lateral plates of arms; *d*, dorsal plates of arms. × 1½.

Protaster. Disc well marked, with fairly large scales. Arms five, long, tapering, without ventral plates; ambulacral ossicles boot-shaped, alternating, not united. Ordovician and Silurian. Ex. *P. sedgwicki*, Silurian.

Lapworthura. Disc circular, well marked. Arms flexible, broad, at first of uniform width, afterwards tapering; ambulacral ossicles opposite, fused, their distal and proximal margins parallel, with plain articular surfaces; ventral arm-plates and buccal plates absent. Madreporic plate dorsal, large. Ludlow Beds. Ex. *L. miltoni*.

Distribution of the Ophiuroidea.

At the present day the majority of the Ophiuroids live in shallow water, more than half of the known species being found above a depth of 30 fathoms, and most of these not extending lower. Other forms occur at greater depths, as many as 69 species being found below 1000 fathoms.

Ophiuroids are rare as fossils; the earliest known form occurs in the Bala Beds, and belongs to the genus *Protaster*; this genus ranges on to the Silurian, where *Lapworthura, Eucladia* and others appear. In the Devonian, *Furcaster* and several other genera are found; in the Trias, *Aspidura.* In the Jurassic we find *Geocoma,* and forms which have been referred to the existing genera *Ophiura, Ophiolepis* and *Ophiocten.* A few, such as *Ophioglypha,* occur in the Eocene.

CLASS III. ECHINOIDEA.

The Echinoids or sea-urchins have usually a globular, heart-shaped, or discoidal body, covered with spines. The shell or test is covered by a layer of ectoderm and consists of numerous calcareous plates, which, in the majority of cases, are immovably united. Nothing corresponding to the ambulacral groove of the star-fish is to be seen on the surface, since the water-vascular system is internal to the skeleton, and as a result the tube-feet, in order to reach the exterior, must pierce the plates of the test. With one exception the mouth is always on the inferior surface; it is either central or placed in front of the centre. The anus is either at the summit of the test or posterior to it, somewhere along a line drawn from the summit to the centre of the base. In the regular echinoids both anus and mouth are central —being placed at opposite poles of the test; in the irregular echinoids the anus is always excentric, and often also the mouth. In the test we may distinguish three parts: a small patch of plates placed at the summit, known as the *apical disc* or *apical system*; a series of plates surrounding the mouth; and the remainder of the test termed the *corona.*

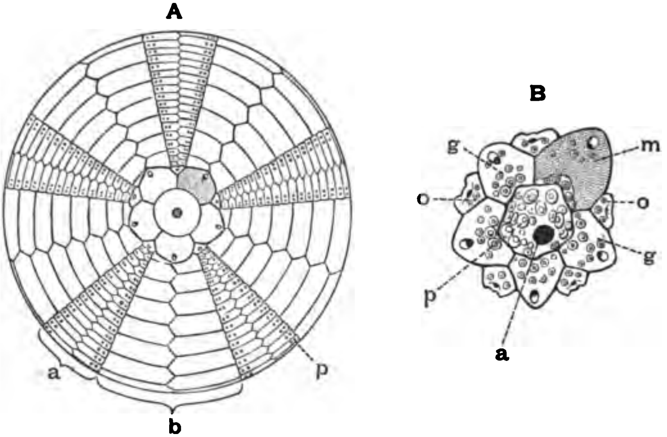

FIG. 42. *A.* Diagram of the upper surface of a regular echinoid, with the tubercles and spines omitted. *a*, ambulacral areas; *b*, interambulacral areas; *p*, pores in the ambulacral plates.

B. Apical disc of *Echinus esculentus*, Recent. *a*, anus; *p*, periproct; *g*, genital plates, each with a pore; *m*, madreporic plate; *o*, ocular plates. Enlarged.

In a typical echinoid of the regular group (*e.g. Echinus*) the anus is placed within the apical disc (fig. 42 *B*), which then consists of the following parts. Near the centre is the anus (*a*), which is surrounded by a membrane covered with scaly plates and known as the *periproct* (*p*). The periproct is encircled by a ring formed of ten plates, five are called *genital* (*g*) and five *ocular* (*o*). The genital plates form the inner part of the ring; they are often more or less hexagonal in outline, and are usually provided with a pore which serves as the opening for the genital ducts—

whence their name; one has a porous structure and functions as the madreporic plate (*m*). Outside the genital plates and alternating with them are the ocular plates; these are smaller than the genital and usually triangular or pentagonal, and each has a perforation through which the termination of the radial water-vessel projects, bearing at its tip what has been regarded as a rudimentary eye[1].

In most of the regular echinoids the apical disc is large, but particularly so in *Cidaris*, *Salenia*, *Peltastes*, and their allies. In a few regular forms (*e.g. Palæchinus*, fig. 43 *D*) the genital plates are completely separated from

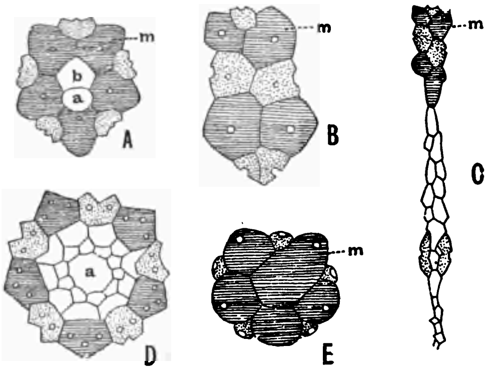

FIG. 43. Some types of apical disc. *A. Peltastes wrighti*, Lower Greensand. *B. Echinocorys vulgaris*, Upper Chalk. *C. Collyrites bicordata*, Corallian. *D. Palæechinus*, Carboniferous Limestone. *E. Galerites subrotundus*, Chalk. In the figures the ocular plates are distinguished by dots, the genital plates by lines. *m*, madreporic plate; *a*, anus; *b*, sur-anal plate. All enlarged.

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[1] The genital plates are sometimes termed *basals* and the oculars are also known as *radials*, since, by some authors, they have been considered to represent the plates which bear the same names in other groups of the Echinoderma. It is more probable that, although occupying similar positions, they have originated independently in the different groups.

one another by the oculars, so that a single row of ten plates encircles the periproct. Each genital plate has usually one perforation only, but in many Palæozoic forms (fig. 43 *D*) there are three, and in *Cidaris* often two. Similarly the oculars in some Palæozoic echinoids have two perforations instead of one. In *Salenia* and *Peltastes* there is an extra plate in the apical disc known as the *sur-anal* or *dorso-central* plate (fig. 43 *A*, *b*); in the young of echinoids this plate occupies all the centre of the disc, but is usually not distinguishable in the adults; in these two genera, however, it is retained throughout life.

In the irregular echinoids the apical disc is small, since it does not enclose the periproct. The madreporic plate extends to the centre of the disc (fig. 43 *E*, *m*), and sometimes (*Spatangus*) reaches to the posterior border, separating the posterior oculars. The posterior genital is sometimes absent (fig. 43 *B*), and when present may be without a perforation (fig. 43 *E*). In *Echinocorys* and *Holaster* the apical disc is elongated, owing to the anterior genitals being separated from the posterior genitals by two oculars which join in the middle (fig. 43 *B*); in *Collyrites* (*C*) the apical disc is still more elongated, since the two posterior oculars are separated from the rest of the apical disc by a chain of small plates.

The corona consists of twenty rows of plates, each row extending from the apical disc to near the mouth. The plates are of two kinds, *ambulacral* (fig. 42 *A*, *a*) and *interambulacral* (*b*); they are arranged in pairs, there being five double rows of ambulacrals separated by five double rows of interambulacrals; each double row is termed an *area*. The former end against the ocular plates, the latter against the genital, and in each case fresh plates are developed next the apical disc. In each area the plates alternate on either side, and since their inner ends are angular, the line between the two rows is zig-zag.

The ambulacral plates are smaller and more numerous than the interambulacral, and they are perforated by pores (*p*) for the passage of the tube-feet to the exterior, a radial water-vessel being placed under each ambulacral area. The pores may be round or elongated; they are situated in the outer portion of the plates and are almost always in pairs; each pair of pores corresponds to a single tube-foot, since each tube-foot divides at its base into two canals. Frequently each pair of pores is surrounded by an oval raised rim (fig. 44). In some echinoids, such as *Cidaris*, each ambulacral plate is formed of one piece only (as in the diagram fig. 42)—such plates are called *simple primaries*. In other cases some of the ambulacral plates are compound, consisting of several small plates which have become fused together; but the original plates are still indicated by the lines of suture between them and also by the pair of pores on each (fig. 44); in some echinoids (fig. 44 *A*) the plates which are united are all primaries—that is to say each extends from the margin to the middle line of the ambulacral area; but frequently some of the plates taper away and do not reach the middle line (or inner edge of the compound plate)—such are called *demi-plates* (*e.g.* three middle plates in fig. 44 *B*). This fusion of plates is usually stated to be due to growth-pressure—since each plate of the test is enlarging and new plates are being added next

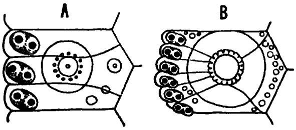

FIG. 44. Compound Ambulacral Plates. *A*. *Pseudodiadema hemisphæricum*, from the Corallian, formed of three fused plates. *B*. *Cyphosoma kœnigi*, from the Chalk, formed of six fused plates. Enlarged.

the apical disc; the fact that some of the fused primary plates are smaller than others, and also the presence of demi-plates, is attributed to the reduction in size of the original plates by the absorption of material under pressure. Lambert, however, explains these facts—fusion and difference in size of plates, mainly by the more rapid superficial growth of the plates on which large tubercles are developed. The pores in the ambulacra of some echinoids are placed one immediately above the other, so that one vertical row of pore-pairs is seen—such pores are termed *unigeminal* (fig. 42); in other cases the pore-pairs are alternately near to, and more distant from the margin of the ambulacral plate, and consequently two vertical rows are formed, and the pores are said to be *bigeminal*; in a similar way three vertical rows of pore-pairs may be produced, when the pores are known as *trigeminal*. Sometimes the pores in each pair are united by a groove on the surface of the plate, and are then termed *conjugate.* In some sea-urchins the two rows of pores in each ambulacral area diverge rapidly after leaving the apical disc, and then come together again before reaching the equator, so that this part of the ambulacrum is leaf-like, and the five ambulacra together form a rosette on the upper surface of the corona, the pores being but irregularly developed on the lower surface; the ambulacral areas in such cases are termed *petaloid* (*e.g. Scutella*), but when the rows of pores diverge but do not come in contact at their lower ends they are *sub-petaloid* (*e.g. Echinobrissus*). When, as in *Cidaris,* the distance between the two rows of pores increases uniformly and slowly in passing from the apical disc to the equator, and the pores are equally well-developed on the under surface of the test, the ambulacra are said to be *simple* (fig. 42).

With only a few exceptions the corona in the Mesozoic and later echinoids is formed of twenty rows of plates, as described above; but in the Palæozoic echinoids, more than twenty rows of plates are found (fig. 47), except in the earliest-known genus *Bothriocidaris* (Ordovician), which is remarkable in having only one row of interambulacral plates in each area, and possesses two rows of ambulacrals. In other Palæozoic forms the number of rows is variable and often great, so that the total number of plates in the corona becomes considerable: thus, *Archæocidaris* possesses two rows of ambulacrals, and from four to seven interambulacrals; *Oligoporus* has four ambulacral and from four to nine interambulacral rows; *Melonechinus,* five to fourteen ambulacral, and from four to eleven interambulacral rows; whilst *Lepidesthes* consists of from eight to as many as eighteen ambulacral, and three to six interambulacral rows. In these Palæozoic forms each ambulacral plate possesses one pair of pores.

In most echinoids the test is rigid, but in several Palæozoic genera, and also in a few later forms (viz. *Pelanechinus,* Corallian; *Echinothuria,* Chalk; and some species of the deep-sea forms *Asthenosoma* and *Phormosoma*) the plates of the corona overlap to a slight extent, giving some flexibility to the test.

The plates of both the ambulacral and interambulacral areas are often provided with rounded elevations known as *tubercles* and *granules.* The tubercles are of various sizes, the largest being the primary. In these the following parts may be distinguished; at the summit there is a spheroidal piece, which is sometimes perforated at the top, and is known as the *mamelon* (fig. 45 *B, m*). The mamelon rests on a short pillar termed the *boss* (*b*), the upper margin of which is sometimes smooth, sometimes crenulated. The base of the boss is frequently surrounded by a smooth excavated space, the *areola* or *scrobicule* (*a*). The granules are smaller than tubercles.

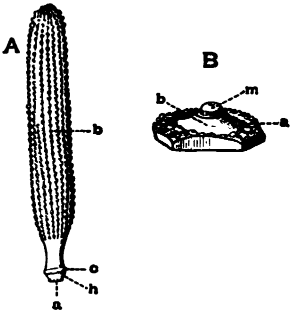

FIG. 45. *A.* Spine of *Cidaris florigemma*, from the Corallian Rocks. *a*, acetabulum; *h*, head; *c*, collar; *b*, body or stem. *B.* Ambulacral plate of *Cidaris* (recent) with a large primary tubercle and secondary tubercles. In the primary tubercle, *m*, mamelon; *b*, boss; *a*, areola. Natural size.

Attached to the tubercles are the *spines*; these are of different sizes and shapes in different genera and species and even on the same individual, being needle-like, rod-like, or flask-shaped; the larger spines are attached to the primary tubercles, the smaller to the secondary tubercles. They serve for protection and also assist in locomotion. At the end of the spine, where it articulates with the mamelon, there is a rounded cavity, the *acetabulum* (fig. 45 *A*, *a*); next comes the *head* (*h*) limited above by a ring or collar (*c*), which may be smooth or crenulated and serves for the attachment of the muscles that move the spine. Beyond the collar and forming the greater part of the spine is the *stem* or body (*b*), which may be smooth, or ornamented with ridges or rows of spiny processes. The microscopic structure of the spines (fig. 37 *A*) varies in different genera, and is of some importance in classification. Pedicellariæ, which consist of a stalk with usually three blades, also occur, but are rarely found fossil.

On the surface of some sea-urchins there are bands, which appear to be nearly smooth, but are covered with very minute tubercles; in the living state they bear slender modified spines. These bands are termed *fascioles*, and their position varies in different genera; sometimes they form a ring beneath the anus (*e.g.* *Micraster*, fig. 46, *c*), when they are said to be *sub-anal*; in other cases they encircle the rosette formed by the petaloid ambulacra (*e.g.* *Hemiaster*) and are said to be *peripetalous*; or they extend round the margin of the test (*e.g.* *Epiaster*).

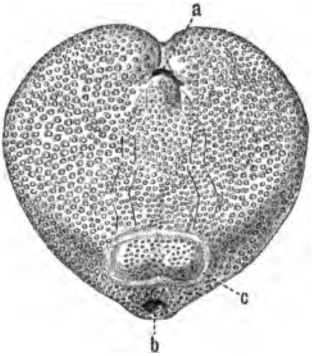

FIG. 46. Under surface of *Micraster cor-anguinum* from the Upper Chalk, showing fasciole. *a*, peristome; *b*, periproct; *c*, fasciole. × ¾.

The mouth is placed in the centre of a membrane known as the *peristome*; this is sometimes (*e.g.* *Cidaris*) completely covered with rows of scaly plates, but more usually bears small isolated plates only. The peristome is usually lost in fossil specimens, and consequently the aperture which is found does not represent the mouth only, but the peristome. The shape of the peristome varies in different genera, it may be circular, oval, pentagonal, or decagonal; at its margin there are frequently ten notches, by which the five pairs of gills or branchiæ pass to the exterior. The peristome is usually larger in the regular than in the irregular echinoids.

At the commencement of the alimentary canal there is, in some genera, a complicated calcareous apparatus which functions in mastication; this is composed chiefly of five jaws, which are moved by means of muscles attached to ridges at the margin of the peristome—these ridges constitute what is known as the *perignathic girdle.* This may consist of ridges arising from the interambulacral plates only, or there may be also processes from the sides of the ambulacral plates, and these often unite, forming an arch or *auricle* over each ambulacral area at the margin of the peristome. The first part of the alimentary canal passes through the centre of the masticatory apparatus. The circular vessel of the water-vascular system forms a ring round the œsophagus at the top of the masticatory apparatus; this ring gives off five radial branches which pass through the auricles and up the inside of each ambulacral area.

In the irregular echinoids there is a well-marked bilateral symmetry; a plane which passes through the anus (which is in the posterior interambulacral area), the apical disc, and the mouth, divides the body into two similar parts. The ambulacra in these forms often differ considerably in size, and, to some extent in structure; the anterior one may be smaller than the others and frequently has a different arrangement of pores, while the four other ambulacra are paired. The interambulacra are also unlike—the posterior one often forming a large part of the base of the test. The bilateral character is not conspicuous in the regular sea-urchins, but the plane of symmetry may be found by means of the madreporic plate, which is always placed at the upper end of the right anterior interambulacral area.

By most writers the Echinoidea have been divided into two Orders, (1) the Palæechinoidea, which are almost exclusively Palæozoic, (2) the Euechinoidea, which are nearly confined to the Neozoic: in the first, the number of rows of plates forming the test varies; in each interambulacral area there is either one[1], or more than two;

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[1] *Bothriocidaris* is the only known genus of echinoid which possesses a single row of plates in each interambulacral area.

in each ambulacral two or many. In the second order, there are two rows of plates in each area. This classification can scarcely be maintained, since it draws a sharp line of separation between *Cidaris* and closely-allied Palæozoic forms; and further, *Tetracidaris* (a Cretaceous Euechinoid) possesses four rows of interambulacral plates.

Other writers recognise two main divisions, termed Gnathostomata and Atelostomata, which are based on the presence or absence of jaws. Another classification, which is adopted here, divides the echinoids into regular and irregular forms; all the regular forms possess jaws; the irregular forms may be divided into two groups according to the presence or absence of jaws.

ORDER I. REGULARES.

The mouth is at the centre of the base, and the anus within the apical disc. The ambulacra are simple. Jaws are present in all. The test is circular in outline.

Palæechinus (fig. 43 *D*). Test spheroidal, rigid. Apical disc with five large genital plates, each with three perforations,—but in some cases one of the genitals may have a single perforation. Ocular plates five, small, each with two perforations. Ambulacra narrow, straight, with two rows of plates, and smaller plates at the margins; two vertical rows of pairs of pores on each side of the area. Interambulacra wide, with five to seven rows of plates at the equator, fewer towards the poles; plates hexagonal, except those next the ambulacral area, which are pentagonal; surface of plates covered with granules. Spines small. Upper Silurian to Carboniferous Limestone. Ex. *P. intermedius*, Carboniferous.

Melonechinus (= *Melonites*) (fig. 47). Test large, elliptical, with furrows from apex to peristome. Apical disc with five genital plates, each having from two to five pores. Ambulacra broad, concave on each side of a median ridge, with five to fourteen columns of plates, each plate with a pair of pores; four plates at the ventral edge of each area. Interambulacra consisting of four to eleven columns of small thick plates, which are pentagonal next the ambulacra, hexagonal elsewhere; tubercles very small. Jaws large. Carboniferous. Ex. *M. multiporus.*

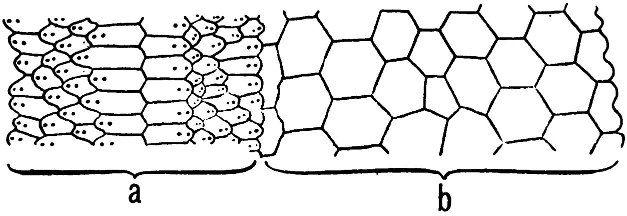

Fig. 47. *Melonechinus multiporus*, Carboniferous. Part of an ambulacral area (*a*) and an interambulacral area (*b*) from the equator of the test. Based on figures given by Jackson. × 2.

Archæocidaris. Test large, plates overlapping. Ambulacra narrow, formed of two rows of plates; pores unigeminal. Interambulacra consist of from four to seven rows of large plates, the middle ones being hexagonal; each plate has a large primary perforated tubercle which bears a long spine. Carboniferous Limestone. Ex. *A. urii.*

Cidaris. Test spheroidal, the summit and base equally flattened. Apical disc very large, rarely preserved fossil, ocular plates large. Ambulacra narrow, undulating, pores unigeminal; between the rows of pores are vertical rows of small tubercles and granules. Interambulacra wide, plates large, each with a primary tubercle which is perforated, and may be crenulated or smooth ; areola large, surrounded by secondary tubercles, beyond which are granules. Peristome rounded. Spines large, of various forms, generally ornamented with rows of granules. Trias to present day. Ex. *C. florigemma*, Corallian and Kimeridgian.

Peltastes (fig. 43 *A*). Test circular in outline, depressed. Apical disc very large, prominent, containing one extra plate, the sur-anal (or dorso-central), placed in front of the periproct; the madreporic plate has an oblique fissure. Ambulacra narrow, straight or slightly flexuous, with small tubercles; pores unigeminal except near the mouth. Interambulacra wide, with large primary tubercles, which are imperforate, but may be crenulate. Peristome slightly notched. Upper Jurassic to Gault. Ex. *P. wrighti*, Lower Cretaceous.

Salenia. Similar to *Peltastes*, but the periproct is placed to the right of a median line drawn from the anterior to the posterior margin. Cretaceous to present day. Ex. *S. petalifera*, Upper Greensand.

Acrosalenia. Form similar to *Peltastes*. Apical disc rather large; genital plates large, the posterior smaller than the others and differing in shape. One or more sur-anal plates in front of the periproct, which is in the antero-posterior line. Pores unigeminal except near the peristome. Interambulacra with large perforate tubercles. Spines smooth or striated. Lias to Cretaceous. Ex. *A. spinosa*, Inferior Oolite to Corallian.

Hemicidaris. Test spheroidal, inferior surface flattened. Apical disc small. Ambulacra narrow, slightly flexuous, with two rows of tubercles below the equator, which pass into granules on the upper surface. Pores unigeminal, but bigeminal near the peristome. Interambulacra broad; plates large and few, each with a large perforated and crenulated tubercle, and also smaller tubercles and granules. Spines cylindrical, long. Peristome large, decagonal. Inferior Oolite to Cretaceous. Ex. *H. intermedia*, Corallian.

Pseudodiadema (fig. 44 *A*). Test circular or slightly polygonal, depressed. Apical disc and periproct large. Ambulacra straight, narrower than the interambulacra, with two rows of crenulate and perforate tubercles; plates compound, each consisting of three fused primaries, the middle being largest, usually with three pairs of pores on each plate, unigeminal. Interambulacra with two or more rows of primary crenulate and perforate tubercles. Peristome large, decagonal. Lias to Tertiary. Ex. *P. ornatum*, Lower Chalk.

Hemipedina. Test circular or slightly polygonal, depressed. Apical disc rather large. Ambulacra narrow, plates formed of three fused primaries (but simple near the apical disc), pores unigeminal; two rows of tubercles, perforate, not crenulate. Interambulacra with two (sometimes more) vertical rows of primary, perforate, not crenulate tubercles. Spines of moderate length, finely grooved. Peristome with slight incisions. Lias to present day. Ex. *H. etheridgei*, Lias.

Diplopodia. Form and tubercles similar to *Pseudodiadema.* Pores bigeminal near the apex and peristome, unigeminal at the equator. Plates at the equator composed of four primary plates or sometimes the lowest plate is a demi-plate. Jurassic and Cretaceous. Ex. *D. versipora*, Corallian.

Stomechinus. Test hemispherical. Genital plates relatively large, projecting outwards; oculars small. Ambulacra wide, plates formed of three primaries—the middle one largest; pores trigeminal. On each ambulacral and interambulacral area are two vertical rows of primary, imperforate, non-crenulate tubercles, of about the same size on each area; also secondary tubercles and granules, usually numerous. Peristome large, with ten deep incisions. Inferior Oolite to Lower Cretaceous. Ex. *S. bigranularis*, Inferior Oolite.

Phymosoma (=*Cyphosoma*) (fig. 44 *B*). Form similar to *Pseudodiadema.* Ambulacral plates compound, each may consist of four, five, or six united plates with the same number of pairs of pores; two rows of primary tubercles. Interambulacra with two or more rows of primary imperforate tubercles. Jurassic to Eocene; common in the Chalk. Ex. *C. kœnigi*, Upper Chalk.

Echinus. Test more or less hemispherical. Apical disc as in fig. 42 *B.* Ambulacra rather narrow, trigeminal, plates consisting of a lower primary, a middle demi-plate, and an upper primary or demi-plate. Two vertical rows of small, primary tubercles on each area, and often numerous secondary tubercles. Peristome rather small, circular, with small incisions. Cretaceous to present day. Ex. *E. woodwardi*, Pliocene; *E. esculentus*, Pliocene and living.

ORDER II. IRREGULARES.

The anus is placed outside the apical disc, in the posterior interambulacral area. The mouth is either central or in front of the centre. The test is bilaterally symmetrical. Ambulacra simple or petaloid. Jaws may be present or absent.

SUB-ORDER 1. GNATHOSTOMATA.

Mouth central. Jaws and perignathic girdle present.

Galerites (=*Echinoconus*) (fig. 43 *E*). Test conical, or almost hemispherical, inferior surface flat, outline pentagonal or oval. Apical disc small. Ambulacra narrow, straight, simple; pores unigeminal, but trigeminal near the mouth. Interambulacra with broad plates, tubercles very small, perforated and crenulated. Peristome small, central, decagonal. Periproct marginal or sub-marginal. Upper Greensand to Upper Chalk. Ex. *G. conicus*, Upper Chalk.

Holectypus. Test hemispherical, depressed, base excavated. Apical disc small. Ambulacra narrow, straight, simple; pores unigeminal, tubercles small. Interambulacra formed of rather large plates, with small tubercles. Peristome central, decagonal. Periproct large, placed between the peristome and the posterior margin of the test. Upper Lias to Corallian; also foreign Cretaceous. Ex. *H. hemisphericus*, Inferior Oolite.

Discoidea. Form similar to *Holectypus*. On the base of the interior are ten vertical plates extending from the margin of the test towards the mouth, and placed on each side of the ambulacral areas. Cretaceous. Ex. *D. cylindrica*, Chalk.

Pygaster. Test large, depressed, outline pentagonal or circular, base concave. Apical disc small, madreporic plate large. Ambulacra straight, simple; pores unigeminal; tubercles in vertical rows. Interambulacra wide, tubercles perforate. Peristome central, large, decagonal. Periproct very large, placed just behind the apical disc. Inferior Oolite to Cretaceous. Ex. *P. umbrella*, Corallian.

SUBORDER 2. ATELOSTOMATA.

No jaws or perignathic girdle. The bilateral symmetry of the test is particularly well-marked.

Hyboclypeus. Test oval, depressed, anterior part usually more elevated. Apical disc elongated—the two anterior genitals separated from the two posterior by two oculars. Ambulacra simple, pores unigeminal. Interambulacra wide. Tubercles very small. Periproct next the apical disc, in a long groove on the dorsal surface. Peristome a little in front of the centre. Inferior Oolite to Corallian. Ex. *H. gibberulus*, Inferior Oolite.

Nucleolites (=*Echinobrissus*). Test depressed; outline oval or quadrilateral, rounded anteriorly, truncated and broadest posteriorly; inferior surface concave. Apical disc compact, four perforate genital plates, and one imperforate. Ambulacra sub-petaloid, pores unigeminal, the outer pore elongated in the sub-petaloid part. Interambulacral plates wide, tubercles small. Peristome oval or pentagonal, excentric, a little anterior. Periproct placed in a sulcus on the dorsal surface. Inferior Oolite to present day. Ex. *N. scutatus*, Corallian.

Clypeus. Test large, flattened, more or less discoidal, with circular or pentagonal outline, and flat or concave base. Apical disc small. Ambulacra large, petaloid, pores unigeminal (except near the peristome), outer pore elongated. Peristome nearly central, with the ambulacra depressed near it. Periproct on the dorsal surface, often in a sulcus. Tubercles very small. Inferior Oolite to Corallian. Ex. *C. ploti*, Inferior Oolite.

Catopygus. Test small, oval, elevated, truncated behind, with flat base. Apical disc small. Ambulacra sub-petaloid, unigeminal, outer pore elongated in the sub-petaloid parts. Tubercles very small. Periproct high up on the posterior end. Peristome a little excentric, small, with ambulacra depressed around it. Cretaceous to present day. Ex. *C. columbarius*, Upper Greensand.

Collyrites (fig. 43 *C*). Test ovoid, inflated. Apical disc greatly elongated; at the anterior end are four perforated genital plates separated by two oculars, at the posterior end are two oculars; these two groups of plates are connected by numerous small plates. Ambulacra simple, pores unigeminal. The three anterior ambulacra meet at the anterior end of the apical disc, the other two meet at the posterior end. Interambulacra broad, tubercles small. Peristome excentric. Periproct above the posterior margin. Upper Lias to Cretaceous. Ex. *C. bicordata*, Corallian.

Echinocorys (=*Ananchytes*) (fig. 43 *B*). Test very convex above, inferior surface flattened, outline oval. Apical disc a little elongated; the four genital plates perforated, the two anterior separated from the two posterior by two ocular plates. Ambulacra simple, pores unigeminal. Interambulacral plates large, tubercles small. Peristome anterior. Periproct oval, infra-marginal. Upper Chalk. Ex. *E. vulgaris.*

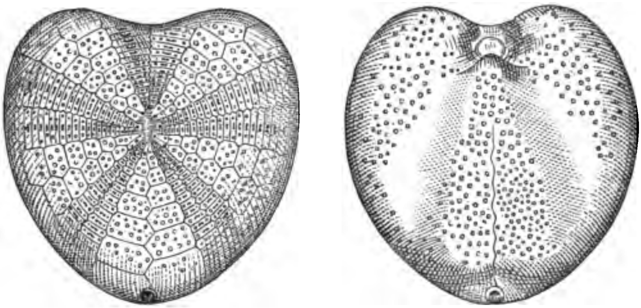

FIG. 48. *Holaster subglobosus*, Chalk. Upper and lower surfaces. × $\frac{2}{3}$.

Holaster (fig. 48). Test heart-shaped, inferior surface more or less flattened, superior surface with a broad shallow groove in front. Apical disc elongate, the two pairs of genital plates separated by two oculars. Ambulacra large, simple, pores unigeminal, round or elongate; the anterior ambulacrum in the groove. Interambulacra with small tubercles and granules. Peristome near the anterior margin, elliptical. Periproct supra-marginal. Upper Greensand and Chalk; also Tertiary in Australia. Ex. *H. subglobosus*, Lower Chalk.

Cardiaster. Form similar to *Holaster*, but anterior groove usually with sharp borders. Apical disc similar to *Holaster*. Pores elongate. Small perforate and crenulate tubercles. Peristome near the anterior margin, with a projecting lip. Periproct on the posterior truncated end. Fasciole passes beneath the periproct and round the margin of the test. Cretaceous. Ex. *C. ananchytis*, Chalk.

Micraster (figs. 46, 49). Test heart-shaped or oval. Apical disc small, excentric. Ambulacra sub-petaloid, placed in sunken areas, the sub-petaloid parts of the two anterior-lateral longer than those of the two postèrior-lateral; pores unigeminal. The anterior unpaired ambulacrum in a deep groove, with its pores circular. Interambulacra with large plates; tubercles small, perforate and crenulate. A fasciole placed below the anus. Peristome excentric, near the anterior border, with a projecting lip. Periproct above the margin. Middle and Upper Chalk; also Tertiary in Australia. Ex. *M. cor-anguinum*, Upper Chalk.

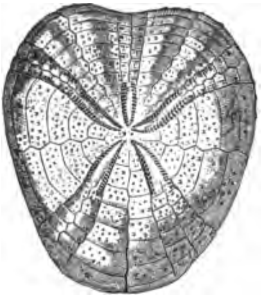

FIG. 49. *Micraster cor-bovis.* Upper Chalk. × ½.

Hemiaster. Form similar to *Micraster.* A peripetalous fasciole only. Cretaceous to present day. Ex. *H. bailyi*, Gault.

Schizaster. Test heart-shaped, highest behind, with excentric apex. Anterior ambulacrum long, placed in a groove; other ambulacra petaloid and in deep grooves—the posterior pair much shorter than the antero-lateral pair. Peristome near the anterior margin with projecting lip. Periproct on the posterior truncated end of the test. A peripetalous fasciole, and usually also a lateral fasciole diverging from the former and passing beneath the periproct. Eocene to present day. Ex. *S. d'urbani*, Bracklesham Beds.

Distribution of the Echinoidea.

Some Echinoids live at great depths in the ocean, no less than a dozen species having been found below the 2000 fathom line, and one even at 2900 fathoms; but by far the larger number occur near the coasts in shallow water: thus, of the 297 existing species recorded by Agassiz, 201 are found in water of less than 150 fathoms in depth. Echinoids are most abundant where the sea-bottom is rocky, sandy, or calcareous, and less common where it is muddy; consequently fossil forms are rare in clayey strata. Those found in deep water have a much wider range in space than those found in shallow water. Many genera, especially those with a considerable range in depth, have also a long range in time, some extending back to the Cretaceous or even earlier periods. Amongst the forms found in the Cretaceous which are still existing in deep water may be mentioned *Salenia*, *Cottaldia*, *Hemiaster*, and *Pygaster*.

All the Palæozoic echinoids, with the possible exception of *Echinocystis*, in which the apical disc is poorly developed, belong to the regular group; they are remarkable for possessing more than twenty rows of plates in the corona (except in *Bothriocidaris*), and frequently the plates overlap, rendering the test flexible. Echinoids are rare in Palæozoic formations, especially in those of pre-Carboniferous age. The earliest form is *Bothriocidaris*, found in the Ordovician rocks of Esthonia in Russia. In the Silurian we get *Palæechinus*, *Echinocystis*, and *Palæodiscus*; in the Devonian, *Lepidocentrus*; in the Carboniferous, *Palæechinus*, *Melonechinus* (= *Melonites*), *Perischodomus*, and *Archæocidaris*. Forms related to *Cidaris* are common in the Trias of St Cassian.

In the Jurassic rocks the echinoids are much more numerous, relatively to the other groups of animals, than in the earlier formations; they are comparatively rare in the Lias and the other clayey divisions, but very abundant in the calcareous beds, especially in the Inferior Oolite and the Corallian. In the Lias the chief forms are *Cidaris*, *Hemipedina*, *Pseudodiadema*, and *Acrosalenia*; irregular echinoids (viz. *Holectypus*, *Collyrites*, and *Galeropygus*) make their first appearance in the Upper Lias. The genera which are best represented in the Middle and Upper Jurassic are, of the regular group, *Cidaris*, *Hemicidaris*, *Acrosalenia*, *Pseudodiadema*, *Diplopodia*, *Hemipedina*, and *Stomechinus*; of the irregular group, *Collyrites*, *Clypeus*, *Pygurus*, *Hyboclypeus*, *Nucleolites* (= *Echinobrissus*), *Holectypus*, and *Pygaster*.

In the Cretaceous the echinoids are even more abundant than in the Jurassic, and attain their greatest development in the upper division of the system; many of the genera found in the Lower Cretaceous occur also in the Upper Jurassic, but the irregular forms are more numerous than hitherto. The most important genera are, (1) regular, *Cidaris*, *Pseudodiadema*, *Phymosoma* (= *Cyphosoma*), *Peltastes*, *Salenia*, (2) irregular, *Discoidea*, *Galerites* (= *Echinoconus*), *Hemiaster*, *Micraster*, *Cardiaster*, *Holaster*, *Echinocorys* (= *Ananchytes*).

Between the Cretaceous and the Eocene there is, in Britain, an enormous break in the succession of the echinoids, not a single species being common to the two systems, and the genera also are mostly different. This change is due in part to the great difference in the conditions under which the deposits were formed, the Chalk being a comparatively deep-water formation, and the Eocene beds, shallow water; but the Eocene forms differ much more from those of the Upper Chalk than from those of the Chalk Marl, the latter deposit having been formed in water of less depth. Throughout the English Tertiaries the echinoids are much rarer than in the Cretaceous; thus in the Cretaceous there are thirty genera, in the Eocene seven, in the Pliocene eleven. In the Eocene this can be accounted for largely by the fact that the sea-bottom was for the most part muddy; in the Pliocene by the lower temperature of the ocean. The London Clay echinoids belong to tropical or sub-tropical genera. The commonest forms in the Eocene of England are *Hemiaster* and *Schizaster*. In the Eocene of the South of Europe, India, etc., echinoids are numerous; the regular forms are less important than in earlier formations, but the Atelostomata, in this and subsequent deposits, become increasingly abundant.

The Pliocene echinoids found in East Anglia present a considerable affinity to those now living in the West Indian seas, probably indicating the existence, at that period, of shallow water between Europe and America in which migration could take place. The most important genera in the Pliocene are *Echinus, Echinocyamus, Spatangus*, and *Temnechinus*.

CLASS IV. HOLOTHUROIDEA.

This Class includes the sea-cucumbers. They possess an elongated and usually cylindrical body with the mouth at one end and the anus at the other; around the mouth is a circle of tentacles, which are really modified tube-feet. From the water-vascular ring five radial vessels are given off, and branches also go to the tentacles. In *Synapta* and its allies tube-feet (with the exception of the tentacles), as well as radial vessels, are absent. The stone-canal in almost all cases opens into the body-cavity. The integument is leathery, and the skeleton is very poorly developed, consisting of minute isolated pieces of various shapes, such as spicules, anchors, and wheels (fig. 50).

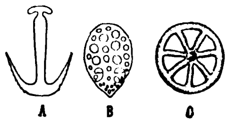

FIG. 50. *A, B*, Anchor and plate of *Synapta tenera*, Recent. *C*, wheel of *Chirodota convexa* from the Inferior Oolite. Enlarged.

At the present day the Holothurians are widely distributed, but owing to the nature of their hard parts they are rarely found fossil. The earliest known forms occur in the Carboniferous rocks of Scotland, and a few specimens have been recorded from Jurassic and later formations.

II. PELMATOZOA.

CLASS I. CRINOIDEA.

The Crinoidea or sea-lilies and feather-stars differ from the preceding groups of Echinoderms in having the oral surface directed upwards and the dorsal surface downwards; in most forms the animal is fixed by means of a stem given off from the dorsal surface, but in some cases the young form only is fixed[1], the adult being free. The skeleton consists of a *stem*, a *calyx*, and movable *arms* given off from the margin of the calyx (fig. 51).

The calyx is more or less globular, or cup- or basin-shaped, and contains the digestive and other important organs; the mouth is either at or near the centre of the ventral or oral surface, and the anus, which is excentric and inter-radial, is also on the oral surface, and is usually situated at the end of a tubular process. There is a groove on the ventral surface of each arm, and these grooves—the *food* or *ambulacral grooves*, are continued over the oral surface to the mouth; they are lined with cilia, by the movements of which food is conveyed to the mouth. The arms are often numerous, owing to repeated branching. Immediately under the groove of each arm there is a radial nerve-cord; these cords unite to form larger trunks and ultimately join as a ring round the mouth. Beneath the nerve of each arm there is a radial vessel of the water-vascular system, which is continued over the oral surface and joins a ring round the mouth; from this ring tubes hang down and open into the body-cavity, which communicates with the water of the exterior by means of pores. In connection with the radial vessels are tubular processes, the tentacles, which form a row on each side of the food-grooves, and correspond with the tube-feet of the star-fish, but do not function in locomotion. In addition to the nervous system already mentioned, there is another placed dorsally in the lower part of the calyx, between the basal plates, or in the centro-dorsal plate (*i.e.* one of the stem-plates which in some forms has become incorporated into the calyx); from this centre cords are given off, which pass through canals in the plates of the calyx to the arms and pinnules, and also into the stem when present. The various plates of the skeleton are held together by fibres of connective tissue.

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[1] There is no evidence to shew that *Marsupites* possessed a stem even in the young state.

The stem (figs. 51, 53, *a*) in the crinoids is more or less flexible, and is sometimes several feet in length. It consists of a number of segments which may be in the form of circular or pentagonal (occasionally square or elliptical) plates; or they may be higher than broad, forming cylinders; these plates or ossicles articulate by their flat surfaces, which are often provided with radiating striæ or with ridges in the form of a rosette. Each plate is pierced at the centre by a canal which is circular or pentagonal and contains a prolongation of the dorsal nervous system and vascular organ. From the stem small branches known as *cirri* are sometimes given off; these have a structure similar to that of the stem, and are also pierced by a central canal. The plates in the stem are generally of different heights—larger plates being separated by smaller;

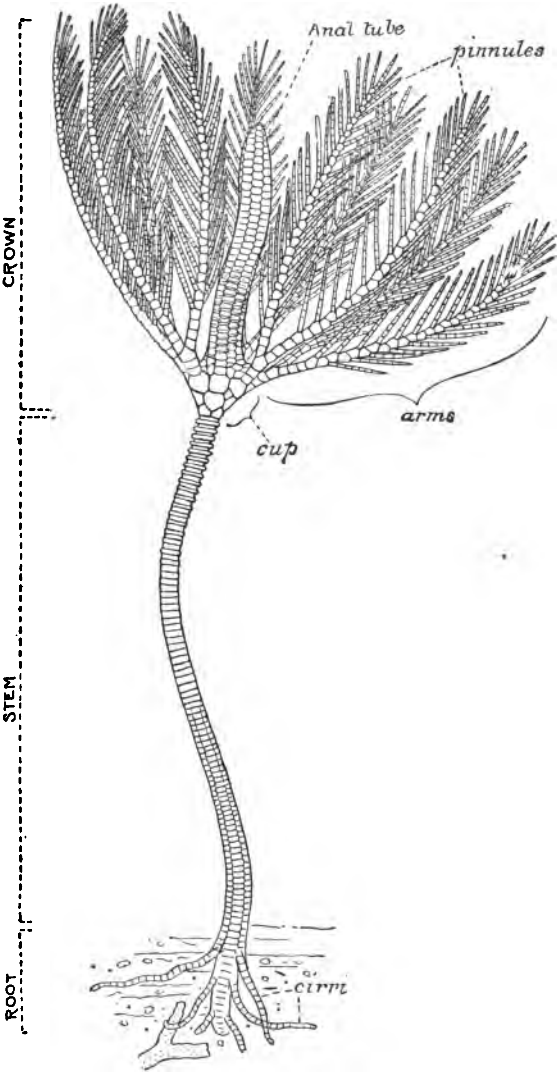

FIG. 51. *Botryocrinus decadactylus*, from the Wenlock Limestone—a simple form of Crinoid, seen from the posterior inter-radius. (From the *Guide to the Geol. Dept., Brit. Mus.*) Natural size.

the former are first developed, the latter being subsequently introduced between them. Cirri are borne on some of the larger plates. The lower end of the stem may taper, but often expands and branches, forming a root-like structure which serves to fix the animal. Sometimes the plates near the top of the stem are very much larger than the others (fig. 54).

The part of the calyx below the origin of the free arms is called the *dorsal cup*; the part above them is the *tegmen.* The dorsal cup consists at its base of a cycle of five plates, known as *basals* (fig. 52, *b*; 53, *c*); but, owing to fusion, the number of basals is sometimes reduced to four, three, or rarely two. In some forms there is below the basals and alternating with them another row of plates (five or three), termed *infra-basals* (fig. 53, *b*), and the base is then said to be *dicyclic*; when basals only are present, it is *monocyclic.* Above the basals, and alternating with them, is a cycle of five *radial* plates (fig. 52, *r* 1; fig. 53, *d*). In some genera there are, between the two posterior radials, in a line with the anus above, other plates, the *inter-radials* (fig. 52, *a*; fig. 53, *e*).

The arms come off directly from the radials, and are formed either of a single or of a double row of plates, the *brachials*; when double, the plates alternate with one another. There is a groove on the ventral or inner surface of the brachials, in which the soft parts, above described, are placed; and there is usually also a perforation below the groove, in which the dorsal nerve-cord is situated. The groove in the arms is covered over by a series of plates—the *ambulacral plates,* which can be opened and closed, and serve for the protection of the soft parts. Where an arm branches, the brachial which supports two branches (figs. 51, 53) has sloping sides, and is known as an *axillare.*

Small unbranched appendages called *pinnules* occur on the arms of many crinoids; they are similar in structure to the arms, and are given off alternately on opposite sides; in living crinoids they bear the genital organs. In some forms, the earlier rows of brachial plates become firmly united to one another and to the radials (figs. 52, 54, *r* 2, *r* 3, *br*); these *fixed brachials* have often been regarded as radials, but morphologically they are only brachials which have become incorporated into the calyx. The fixed brachials may be in contact at the sides, or, as in most Palæozoic crinoids, they may be separated by other plates which are termed *inter-brachials* (fig. 52, *ir*). In the posterior inter-radial area (that which leads up to the anus) the inter-brachial plates are often more numerous than in the other areas. When a stem is absent there is often a central plate at the base of the calyx (*e.g. Marsupites*).

The tegmen or oral surface of the calyx is more or less completely covered by calcareous plates. Sometimes five large triangular plates (*orals*) only occur, between which are the ambulacral grooves; but usually other smaller plates are also present—the ambulacral grooves are usually covered by ambulacral plates, and between them occur numerous interambulacral plates. In many Palæozoic crinoids (*e.g. Actinocrinus*) the tegmen consists of a complete vault or dome of stout plates concealing the mouth as well as the ambulacral grooves and ambulacral plates.

A. *Monocyclic Crinoids.*

Platycrinus. Basals three, unsymmetrical. Radials five, large, tall. Some fixed brachials. One inter-brachial in each area—more in the posterior (anal) area. No inter-radial. Arms bifurcating once to thrice, formed of one row of plates at the lower end but of two above; pinnules long. Tegmen with small plates; anus sub-central, usually at the end of a large process. Stem long, round or elliptical. Devonian, but mainly Carboniferous. Ex. *P. lævis*, Carboniferous Limestone.

Eucalyptocrinus (=*Hypanthocrinus*). Calyx deeply concave at the base; at the bottom of the cavity four basals, at the sides five radials; several cycles of fixed brachials, and some interbrachials. Tegmen elevated, and forming a central anal tube composed of five rows of large plates. Ten vertical partitions are attached to the outside of the tegmen, forming compartments in which the ten arms rest. Arms formed of two rows of brachials except at the base. Silurian and Devonian. Ex. *E. decorus*, Wenlock Limestone.

Actinocrinus (fig. 52). Calyx pear-shaped, ovoid, or more or less spherical. Basals three, equal, forming a hexagon. Radials five, high. The first two rows of brachials firmly united. Interbrachials numerous; and also one (posterior) inter-radial, above which the inter-brachials are more numerous than in the other areas. Tegmen formed of thick, tubercled, hexagonal plates, produced into a tube with the anus at the end. Arms ten to thirty, with two rows of plates. Stem circular, canal pentagonal. Carboniferous. Ex. *A. triacontadactylus*, Carboniferous Limestone.

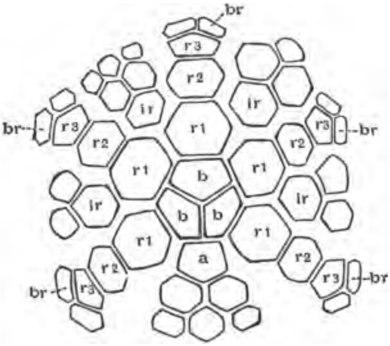

FIG. 52. Diagram of the plates of *Actinocrinus triacontadactylus*, Carboniferous Limestone. *b*, basal plates; *r* 1, radials; *r* 2, *r* 3, fixed brachials; *br*, brachial plates; *ir*, inter-brachials; *a*, inter-radial.

Amphoracrinus. Related to *Actinocrinus.* Calyx depressed, saucer-like or nearly flat. Tegmen much elevated. Three basals, and a posterior inter-radial. Inter-brachials few. Anal tube short, excentric. Carboniferous. Ex. *A. amphora.*

Cyathocrinus (fig. 53). Calyx cup-like. Infra-basals five, small, equal, pentagonal. Basals five, large, hexagonal (except the posterior, which is heptagonal and supports the square inter-radial plate). Radials five, shield-shaped. Arms five, very long, bifurcating from five to seven times, without pinnules. Oral plates five, large. Anal tube formed of more or less hexagonal plates. Stem round, without cirri. Silurian to Carboniferous. Ex. *C. longimanus*, *C. acinotubus*, Silurian.

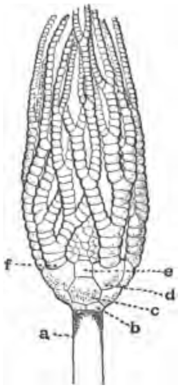

FIG. 53. *Cyathocrinus longimanus*, from the Silurian. *a*, portion of stem; *b*, infra-basal plates; *c*, basals; *d*, radials; *e*, anal inter-radial; *f*, first brachial. Reduced.

B. *Dicyclic Crinoids.*

Crotalocrinus. Infra-basals five, pentagonal. Basals very large, all hexagonal except the posterior one, on which the small inter-radial plate rests. Radials very large. Some fixed brachials. Arms five, with a single row of plates; dichotomous, the branches uniting so as to form lamellar expansions or networks, which are inrolled; pinnules absent. Tegmen nearly flat, formed of small fixed plates with five large plates at the centre. Anal tube near the posterior margin. Stem thick, circular; canal pentagonal; roots thick. Wenlock Limestone. Ex. *C. rugosus.*

Botryocrinus (fig. 51). Calyx small, shallow. Infra-basals five; basals five, hexagonal (except the two posterior, which are pentagonal); radials large, with excavated articular surface; anal inter-radial small, rhomboidal. Arms divide, giving ten main branches bearing smaller branches or pinnules. Anal tube large, often coiled. Stem formed of thin plates. Silurian and Devonian. Ex. *B. decadactylus*, Wenlock Limestone.

Poteriocrinus. Calyx with thin plates. Basals high. Anal inter-radial present. Radials with well-marked concave articular surfaces which do not occupy the entire width of the plates. Anal tube long. Arms long, branching, with pinnules. Devonian and Carboniferous. Ex. *P. granulosus*, Carboniferous.

Woodocrinus. Allied to *Poteriocrinus* but calyx, arms, and anal tube shorter. Carboniferous. Ex. *W. macrodactylus*.

Encrinus. Calyx saucer-shaped. Infra-basals five, very small, generally concealed by the stem. Basals five, pentagonal. Radials five, large, pentagonal; above the radials are the brachials, the first two rows of which are united. No inter-brachials. Arms bifurcating, formed of one row of brachials at first, afterwards of two; with pinnules. Tegmen elevated. Stem long, with small canal. Trias. Ex. *E. liliiformis*, Muschelkalk.

Pentacrinus. Calyx small, bowl-shaped, consisting of five small infra-basals, five basals, and five radials which project like spines over the stem. Arms very long, much branched, formed of a single row of brachials; the small branches all come off on the same side of each main branch. The arms bear pinnules. Stem long, pentagonal, with cirri coming off in whorls; the articular surfaces of the stem-plates with five raised, crenulate, petaloid parts which are narrow and quite distinct from one another. Jurassic. Ex. *P. fossilis*, Lias.

Marsupites. Calyx large, globular, plates large and thin. Stem absent. Base formed of a large central pentagonal plate. Infra-basals five, pentagonal. Basals five, hexagonal. Radials five, pentagonal, with crescentic depressions for the articulation of the arms. Arms relatively short, bifurcating, formed of a single row of plates. Upper Chalk. Ex. *M. testudinarius*.

Ichthyocrinus. Three very small infra-basals; five small basals; five radials; two or three cycles of fixed brachials. No inter-radials and inter-brachials. Arms in contact all round, interlocking, formed of a single row of brachials; no pinnules. Silurian to Carboniferous. Ex. *I. piriformis*, Silurian.

Sagenocrinus. Infra-basals small. Anal inter-radial sunk between basals; radials large. Numerous cycles of fixed brachials, separated by very numerous inter-brachials. Arms dividing, formed of one row of brachials; no pinnules. Silurian. Ex. *S. expansus.*

Apiocrinus (fig. 54). Calyx large. Basals five, thick. Radials low, excavated on their upper surfaces. Four cycles of fixed brachials. Arms ten, bifurcating once or twice, formed of a single row of plates. Stem long, cylindrical, base expanded; the articular surfaces of the plates radiately striated. The plates of the upper part of the stem are in contact at the periphery only. The upper part of the stem expands and passes gradually into the calyx; the upper surface of the last plate is provided with five radiating ridges between which the basals lie. Lias to Lower Cretaceous. Ex. *A. parkinsoni*, Bradford Clay.

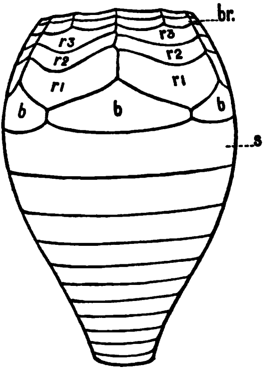

FIG. 54. *Apiocrinus parkinsoni*, from the Bradford Clay. *s*, top plate of the stem; *b*, basal plates; *r* 1, radial plates; *r* 2, *r* 3, and *br*, brachial plates. ×$\frac{3}{4}$.

Millericrinus. Allied to *Apiocrinus.* Top plate of stem widened, but not the others as a rule. Articular facets of radials and brachials well developed. Lias (? also Trias) to Lower Cretaceous. Ex. *M. pratti*, Inferior and Great Oolites.

Bourgueticrinus. Calyx small, with vertical or inwardly-sloping sides; formed of five basals about half the height of radials, and two rows of fixed brachials; no inter-brachials. Arms unknown. Stem long, ossicles long, the top-ossicle very large, as wide as calyx; upper stem-ossicles with circular, others with elliptical articular faces and a transverse ridge across the longer diameter. Cretaceous. Ex. *B. ellipticus*, Chalk.

Distribution of the Crinoidea.

In comparison with its abundance in former times the class Crinoidea is but poorly represented at the present day. The most important families are the Antedonidæ and the Actinometridæ; these are widely distributed, and occur chiefly in shallow water, but some are found at considerable depths—*Antedon* extending from the shore-line down to 2900 fathoms, and *Actinometra* down to 800 fathoms. The stalked crinoids (*e.g. Isocrinus, Rhizocrinus*) are much less abundant than the Antedonidæ and Actinometridæ, and are found mainly at great depths. In most cases the species of crinoids have only a limited distribution in space.

In the Palæozoic formations the crinoids are much more numerous than the other Echinoderms, their remains (chiefly stems) forming the main part of some limestone beds (crinoidal limestone or marble), as for instance in the Carboniferous. None of the other Echinoderms are ever sufficiently abundant to be of importance as rock-builders. The majority of fossil crinoids appear to have lived in fairly shallow water, since they are found in association with reef-building corals and other shallow-water organisms.

Crinoids occur first in the Tremadoc Beds. In the Ordovician, *Glyptocrinus, Dendrocrinus,* and a few others have been found. In the Silurian, crinoids become very much more abundant, and attain their maximum development; the most important genera are *Botryocrinus, Calceocrinus, Crotalocrinus, Eucalyptocrinus, Herpetocrinus, Ichthyocrinus, Marsipocrinus, Mastigocrinus, Pisocrinus, Sagenocrinus, Taxocrinus.* In the Devonian, *Cyathocrinus, Cupressocrinus, Haplocrinus, Hexacrinus* and others are common; in the Carboniferous, *Actinocrinus*, *Amphoracrinus*, *Poteriocrinus*, *Platycrinus*, *Rhodocrinus*, and *Woodocrinus*. Crinoids are rare in the Permian. Throughout the Mesozoic formations they are much less abundant than in the Palæozoic; in the Trias the characteristic form is *Encrinus*. In the Jurassic, *Antedon*, *Pentacrinus*, *Isocrinus*, *Saccocoma*, *Apiocrinus*, and *Millericrinus* are found, the first two living on to the present day. In the Cretaceous the chief forms are *Marsupites*, *Uintacrinus*, and *Bourgueticrinus*. In the Cainozoic, crinoids are very rare.

CLASS II. CYSTIDEA.

The stem in the Cystideans is short, and in some cases absent. The calyx is usually more or less spherical or ovoid, and varies considerably in structure in different types; frequently the plates are very numerous, without radial symmetry, and perforated by numerous canals; food-grooves usually extend from the mouth over the surface of the calyx, and bear simple arm-like structures, called *brachioles* (fig. 56).

In *Glyptosphæra* (fig. 55 *A*), from the Ordovician, the calyx is spherical, and composed of a very large number of polygonal plates, which are without any radial arrangement such as occurs in the Crinoids and Blastoids. The mouth is at the summit of the calyx, and is covered by five oral plates (*a*), between which the five food-grooves start and extend in a radial manner over the upper part of the calyx, sometimes giving off branches (*b*); at the ends of these grooves are tubercles (*c*) to which small arm-like structures or brachioles were articulated. The grooves were protected by small covering-plates. On one side of the calyx is the anus (*d*), which in perfect specimens is covered by a pyramid of small triangular plates. Between the mouth and the anus is the madreporite (*e*), which is

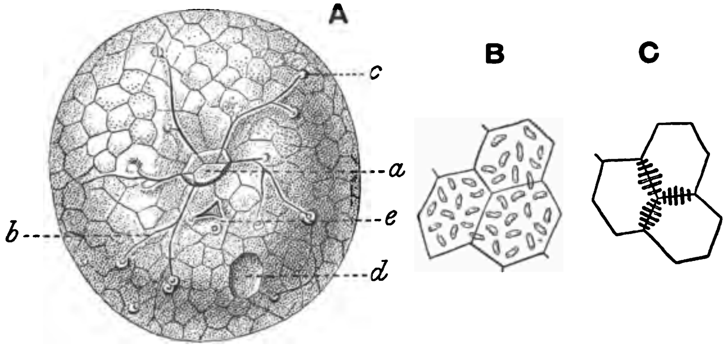

Fig. 55. *A*, *Glyptosphæra leuchtenbergi*, from the Ordovician of Russia. *a*, mouth covered by oral plates; *b*, food-grooves; *c*, socket for the brachiole; *d*, anus; *e*, just above this is the triangular madreporite, just below is the circular genital aperture (after Volborth). *B*, a few plates of the same enlarged, showing the pairs of pores. *C*, Plates of *Echinosphæra*, with pore-rhombs, enlarged.

the external opening of the water-vascular system; just below it is the small circular genital aperture. All the plates of the calyx are pierced by canals running perpendicularly to the surface; the canals are in pairs, and the external openings of each pair are enclosed in a raised or depressed area of oval shape (fig. 55 *B*).

Some Cystideans are more primitive in character than the form just described. For example, *Aristocytis*, from the Ordovician of Bohemia, has an ovoid or pear-shaped body formed of numerous plates, but possesses no food-grooves, brachioles, or stem, and the pores traversing the plates are single.

In another group of the Cystidea the plates of the calyx are traversed by canals which are arranged in groups having a rhombic form; one half of each rhomb is on one plate, the other on an adjoining plate (fig. 55 *C*). The canals are parallel to the surface of the plates, and perpendicular to the sutures between the plates. These groups of canals are known as *pore-rhombs. Echinosphæra,* from the Ordovician, is a form which possesses many pore-rhombs; it has a spherical calyx, consisting of numerous plates, some of which project at the base and probably served to fix the calyx, there being no stem; around the mouth are from three to five small arms. In most genera belonging to this group the plates of the calyx are much fewer in number than in *Echinosphæra,* and have a distinctly radial symmetry—being arranged in cycles, the plates of each cycle alternating with those immediately below. For example, the calyx of *Lepadocrinus,* from the Silurian (fig. 56), is formed of five cycles of plates; at the base is a cycle of four plates, followed by four cycles of five plates each; from the summit of the ovoid calyx four food-grooves stretch toward the base; they do not rest directly on the calyx, as is the case in *Glyptosphæra,* but on specially-developed plates. Numerous brachioles

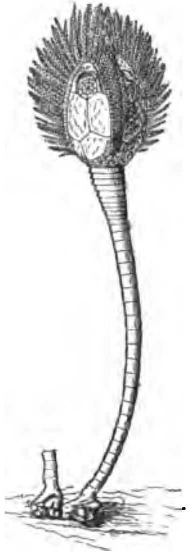

FIG. 56. *Lepadocrinus quadrifasciatus,* from the Wenlock Limestone. Restored figure. The brachioles of the outer rows are erect; those of the middle row depressed. Near the top of the left-hand quarter is the anus; near the top of the right-hand quarter is a pectinated rhomb. (From the *Guide to the Geol. Dept., Brit. Mus.*) Natural size.

come off from each side of the food-grooves. In this genus there are only three rhombs, and they are of the more highly-developed type called *pectinated rhombs*; these differ from pore-rhombs in being surrounded by a raised rim and in having the folds of the plate more pronounced. In some other Cystideans of this group the brachioles are found near the mouth only.

Distribution of the Cystidea.

The Cystideans are comparatively rare fossils. They range from the Middle Cambrian to the Carboniferous Limestone, and attain their maximum development in the Upper Ordovician. In the Menevian we get *Protocystis*; this also occurs in the Tremadoc Beds, and with it *Macrocystella.* In the Ordovician we find, amongst others, *Aristocystis, Echinosphæra, Pleurocystis,* and *Glyptosphæra*; in the Silurian, *Lepadocrinus, Pseudocrinus,* and *Placocystis.* In the Devonian there are fewer forms, and from the Carboniferous only one or two genera have been recorded.

CLASS III. BLASTOIDEA.

In the Blastoids (fig. 57) the body consists of a calyx, usually with a stem; but the latter is rarely found attached to the calyx. The calyx may be spherical, oval, pear-shaped, or bud-like; in most cases it is formed almost entirely of thirteen plates, arranged in a regular manner. True arms are not present.

In *Pentremites,* which may be taken as a type of the group, the calyx (fig. 58) has the following structure. The dorsal part is formed of a cycle of three plates—the *basals* (*b*), two of which are alike, and the third smaller. Above the basals is a cycle of five *radial plates* (*r*); these are

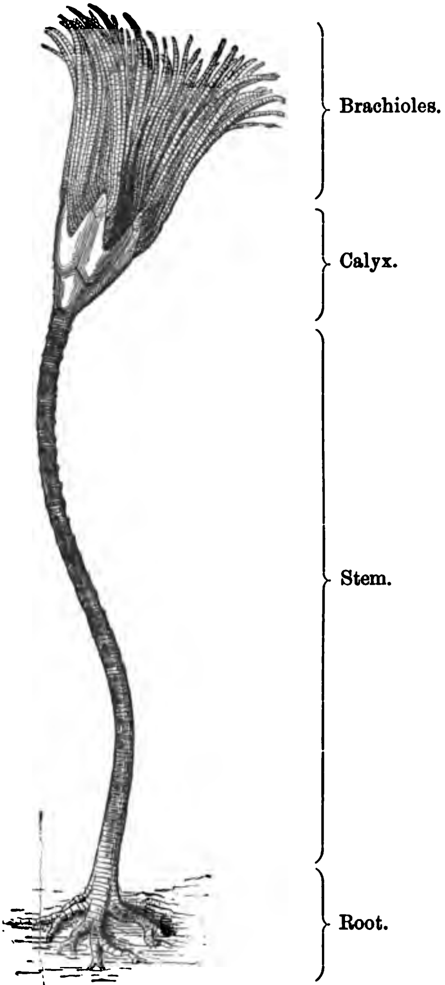

Fig. 57. *Orophocrinus fusiformis*, from the Carboniferous of Iowa. Restored figure. (From the *Guide to the Geol. Dept.*, *Brit. Mus.*) Natural size.

larger than the basals, and form the main part of the calyx. At the upper end of each there is a deep incision, which serves for the reception of the ambulacral area (*a*). Above the radials and alternating with them occurs a cycle of smaller plates—the *deltoids* (*d*) or inter-radials.

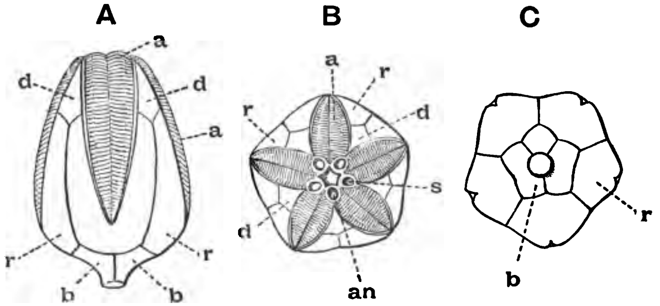

FIG. 58. *Pentremites godoni*, Carboniferous. *A*, side; *B*, upper surface; *C*, under surface. *a*, ambulacral areas; *b*, basal plates; *r*, radials; *d*, deltoids; *s*, spiracles around the mouth; *an*, anus. × 2.

The mouth is placed at the summit of the calyx, in the centre, and around it are five other apertures termed *spiracles* (*s*), one of which is larger than the others and includes the anus (*an*). From the summit the five ambulacral areas (*a*) radiate towards the dorsal surface, and are bordered partly by the deltoids but mainly by the radials. Each ambulacral area (fig. 59) consists of the following plates. Occupying the middle is a long pointed plate (*l*), the *lancet-plate*, which is

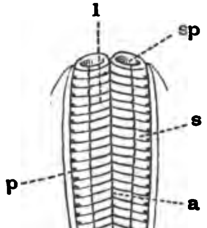

FIG. 59. Ambulacral area of *Pentremites godoni*, Carboniferous. *l*, lancet-plate; *s*, side-plate; *p*, pore; *a*, ambulacral groove; *sp*. spiracle. × 3.

traversed by a longitudinal canal, in which the radial vessel of the water-vascular system was probably placed. On each side of the lancet-plate is a row of small plates, the *side-plates* (*s*). Extending down the middle of each ambulacral area is a groove, the *ambulacral groove* (*a*), which, in perfect specimens, is covered over by small calcareous plates. At right angles to the ambulacral groove, on each side of it, are numerous transverse grooves. Along the outer margin of the side-plates there is a row of pores, the *marginal pores* (*p*), formed by spaces between adjoining plates. When the lancet-plate and the side-plates are removed from an ambulacral area, we find underneath, in the middle line, an elongated trough-like plate, known as the *under-lancet-plate.* At the sides of this may be seen the edges of the *hydrospire* (fig. 60 *h*), which consists of a flattened and folded calcareous tube, communicating with the exterior by means of the marginal pores, and ventrally also by the spiracles. A current of water probably passed in through the former openings and out by the latter. In well-preserved specimens the mouth, as in many crinoids, is not visible externally, but is covered over by a roof of small plates. From the margins of the ambulacral areas pinnule-like appendages known as *brachioles* (fig. 57) are given off; these are seldom preserved, but pits or tubercles to which they were attached are seen on the side-plates.

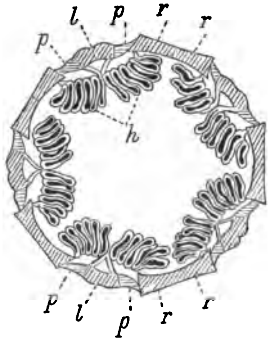

Fig. 60. *Pentremites sulcatus,* Carboniferous. Horizontal section of the calyx. *l*, lancet-plate; *p*, side-plates; *r*, radial plates; *h*, hydrospires. (After Zittel.) Enlarged.

One of the chief differences seen in other genera of blastoids is in the structure of the hydrospire; in a few primitive types this organ is absent; in other cases (*e.g. Codaster*) it is formed by the folding of the wall of the calyx (deltoids and radials) and opens at the surface by slits instead of marginal pores. In forms (*e.g. Pentremites*) in which the hydrospire has the appearance of a flattened and folded tube, hanging into the cavity of the calyx, the number of folds varies from one to many. Spiracles are sometimes absent (*Codaster*), but frequently five pairs occur with an independent anus; in *Pentremites* the pairs have united and the anus is included in the posterior spiracle. The ambulacra vary in width and length; they may be broad and petaloid or narrow and linear. In addition to side-plates, smaller plates may be present at the ambulacral margins and are called *outer-side-plates.* The side-plates may be entirely at the sides of the lancet-plate, or they may rest on it and partly, or even completely, conceal it. The under-lancet-plate is sometimes absent. The relative sizes of the basals, radials, and deltoids also vary considerably—thus the deltoids may be very small (*e.g. Troostocrinus*), or they may form a considerable part of the calyx (*Orbitremites*).

The most important characters of the Blastoidea as a class are found in the ambulacra and hydrospires, the absence of true arms, the monocyclic base consisting of three basals only, and the five incised radials. In a few rare cases, hydrospires have been found to be present in the Crinoidea (*Carabocrinus, Hybocrinus*).

Codaster. Calyx in the form of an inverted cone or pyramid. Basals forming a conical and usually deep cup; radials large, with the forked parts sharply bent, forming part of the flattened upper surface of the calyx; deltoids and ambulacra confined to upper surface. A long lancet-plate, with side-plates, occurs between the deltoids and radials. Hydrospires consist of sharp folds of the calyx where the radials and deltoids meet, and open at the surface by slits. Mouth pentagonal, originally plated over; no spiracles; anus between the posterior deltoid and radials. Silurian to Carboniferous. Ex. *C. trilobatus*, Carboniferous.

Orbitremites (=*Granatocrinus*). Calyx elliptical, ovate, or more or less spherical, in section pentagonal or round; with concave base. Basals small, not seen in a side view. Radials of variable size and forming part of the base. Deltoids generally rhombic, large in some species, small in others. Ambulacra narrow, straight, with nearly parallel sides. Lancet-plate narrow. Hydrospires simple, usually with two or three folds only, dilated at the ends; the inner fold forms a plate next to the lancet-plate. Spiracles five, round or oval, piercing the apices of the deltoids, the posterior one including the anus. Carboniferous Limestone. Ex. *O. derbiensis.*

Distribution of the Blastoidea.

In England the Blastoids range from the Devonian to the Carboniferous, being most abundant in the latter. A few primitive types (*Asteroblastus, Blastoidocrinus*) occur in the Ordovician of Russia and Canada; and some others (*Troostocrinus, Codaster*) are found in the Silurian of North America. The English Devonian forms are rare and but little known. In the Carboniferous Limestone the blastoids attain their maximum development; ten genera are represented, the most important being *Codaster, Orophocrinus, Schizoblastus, Orbitremites* and *Mesoblastus*. *Pentremites* is common in the Carboniferous of America, but is not found in Britain.

CLASS IV. EDRIOASTEROIDEA.

The calyx in the Edrioasteroids (fig. 61 *A*) is usually composed of a large number of irregular plates, but, unlike the Cystidea, the canals (*p*) do not pass *through* the plates but *between* them. In most cases the calyx is flattened and more or less circular in outline; it is attached to some foreign body by the under-part—a stem being very rarely present. The mouth is at the centre of the upper surface (*ps*), and is covered by oral plates; from it five ambulacral grooves extend outwards over the upper surface of the calyx, and sometimes over part of the lower surface also. The ambulacra do not branch, but are frequently curved. The ambulacral grooves are covered by two rows of alternating plates (*amb*), similar to the ambulacral

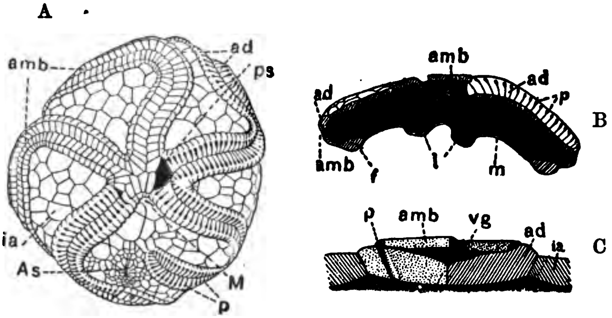

FIG. 61. *Edrioaster bigsbyi*, from the Ordovician of Canada. (From F. A. Bather, *Echinoderma* in Lankester's *Zoology*, part III.)

A, oral surface. *amb*, covering-plates over the anterior and left-anterior ambulacral grooves, but removed from the other grooves; *ad*, floor-plates of ambulacral grooves; *p*, pores between floor-plates; *ps*, peristome, the greater part of which is roofed by enlarged covering-plates; *ia*, interambulacra; *M*, madreporite; *As*, anus. Natural size.

B, section across the same specimen through the right anterior ambulacrum and the left posterior interambulacrum. Lettering as in *A*. *f*, frame of stouter plates; *m*, membrane with overlapping plates thrown into five lobes (*l*). Natural size.

C, section across an ambulacrum with covering-plates (*amb*) over the groove (*vg*). Enlarged.

plates of crinoids, and the floor of each groove is formed of special plates (*ad*), between or at the outer margins of which the canals pass (*p*). Neither brachioles nor arms are developed in connexion with the ambulacra. The anus, which is covered by a pyramid of plates, as in the Cystidea, is on the upper surface—in the area between the two posterior ambulacra (*As*). The calyx was more or less flexible in some cases; and frequently around its border on the upper surface (but sometimes on the lower, fig. 61 *B*, *f*) there is a series of larger marginal plates, forming a framework, which, in combination with the five conspicuous ambulacra, gives the upper surface something of the appearance of a starfish in which the rays are not prolonged.

The Edrioasteroids include only a few genera, and have usually been regarded as Cystidea, but differ generally in the canals passing between the plates, in the more perfect development of the ambulacra, the absence of brachioles, etc.

Distribution of the Edrioasteroidea.

The Class ranges from the Cambrian to the Carboniferous, and is best represented in the Ordovician. The principal genera are:—*Stromatocystis* in the Cambrian; *Cyathocystis, Edrioaster* and *Steganoblastus* in the Ordovician; and *Agelacrinus* and *Lepidodiscus,* ranging from the Ordovician to the Carboniferous.

PHYLUM ANNELIDA.

CLASS CHÆTOPODA.

The Chætopoda include various forms of 'worms.' The body is segmented and generally the segments are similar. There is a ventral nerve-cord and a ring round the œsophagus connected with a pair of ganglia above it. A vascular system and a body-cavity (cœlom) are present. The Chætopoda possess bristle-like processes termed setæ which assist in locomotion. There are three orders, (1) the Archiannelida, *e.g.* *Polygordius,* (2) the Oligochæta, *e.g.* the common earthworm *Lumbricus,* and (3) the Polychæta. The Archiannelida and the Oligochæta are unknown in the fossil state. The Hirudinea or leeches are regarded by some writers as a distinct Class of the Annelida, but by others as a division of the Chætopoda; they do not occur fossil.

ORDER III. POLYCHÆTA.

The members of this Order are nearly all marine; they are characterised by the possession of numerous setæ, which are placed on special processes termed *parapodia.* Tentacles are usually present on the head. Many forms live in tubes, which may consist of carbonate of lime, of chitinous material, or of grains of sand cemented together by a secretion. On account of the possession of this tube the polychætous worms are often found fossil. Other forms, which do not live in tubes, are provided with minute chitinous jaws, and in some formations, especially the Ordovician and Silurian, these are abundantly preserved.

Serpula. Tube calcareous, long, round, angular or flattened; straight, curved irregularly or sometimes spirally, closed at one end; generally attached to some foreign object by a portion of its surface. Carboniferous to present day. Ex. *S. gordialis*, Chalk.

Spirorbis. Tube calcareous, small, spiral, attached by one side. The spiral either left-handed or right-handed, the last whorl often produced into a free tube. Ordovician to present day. Ex. *S. pusillus* (=*carbonarius*), Carboniferous.

Distribution of the Chætopoda.

Practically all the worms found fossil belong to the Polychæta; the earliest examples occur in the Cambrian beds. In addition to worm-tubes and jaws, we find, in various rocks, numerous trails and burrows, which are considered by some authors to have been formed by worms, but in many cases it is probable that they were made by other animals such as crustaceans and gasteropods.

PHYLUM BRACHIOPODA.

Sub-Classes.	*Orders.*
1. Inarticulata.	1. Atremata.
	2. Neotremata.
2. Articulata.	1. Protremata.
	2. Telotremata.

In the Brachiopods the soft parts of the animal are enclosed in a shell which is formed of two pieces termed *valves*, one placed on the dorsal surface, the other on the ventral. Generally the body occupies only the posterior part of the shell. The interior of the shell is lined by a membrane, the *mantle*, which is a prolongation of the body-wall, and is divided into two lobes, one occurring in each valve; the space between the two is known as the *mantle-cavity*. In most genera the margin of the mantle is thickened, and carries numerous chitinous setæ. The mouth (fig. 62, *v*) opens into the mantle-cavity, and leads into an œsophagus, which is followed by a stomach (partly surrounded by the liver), and an intestine. In the articulate brachiopods the intestine is short and ends blindly, in the inarticulate forms it is long and ends in an anus which opens into the mantle-cavity. The nervous system consists of a ring round the œsophagus, with ganglionic enlargements from which nerves are given off to the arms, mantle, etc. The part of the body-cavity which surrounds the alimentary canal communicates with the mantle-cavity by means of two, or rarely four, funnel-shaped canals, which serve as excretory organs. The body-cavity extends into the mantle as a series of spaces or sinuses; these produce slight depressions on the interior of the valves, and can often be traced as ridges on the internal casts of fossil specimens (fig. 78). The body-cavity is filled with a fluid which is kept in motion by means of cilia. A vesicle found on the dorsal surface of the alimentary canal, near the œsophagus, is regarded as the heart.

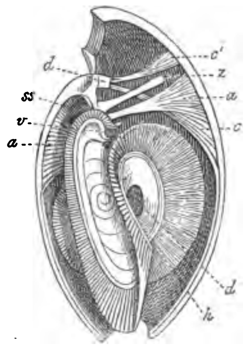

Fig. 62. *Magellania* [= *Waldheimia*] *flavescens*, Recent. Longitudinal section. *d*, (upper), cardinal process; *d*, (lower), arms; *h*, cirri; *a*, adductor muscles; *c*, *c′*, divaricator muscles; *ss*, septum; *v*, mouth; *z*, terminal part of alimentary canal. (After Davidson.) × 1½.

The brachiopods are never colonial animals. Reproduction takes place sexually, never by budding or fission; they are diœcious. The genital organs are placed in the body-cavity, and in the sinuses of the mantle.

Generally the greater part of the mantle-cavity is occupied by two long processes, given off from the sides of the mouth; these are known as the "*arms*" (fig. 62, *d*), since they were at first supposed to serve in locomotion—hence the name *Brachiopoda.* The arms are covered with cirri (*h*), which produce a current of water conveying food to the mouth. Respiration is carried on mainly by the mantle, but possibly also to some extent by the arms.

Of the two valves of the brachiopod, the ventral is nearly always larger than the dorsal; each is produced into a beak or *umbo* (fig. 63). The ventral umbo is more prominent than the dorsal, and it has generally, either at its apex or just beneath it, an opening. With a very few exceptions the shell of the brachiopod is equilateral, that is to say, a line drawn from the umbo to the opposite margin divides it into two equal and similar parts. This character, combined with the inequality in the size of the valves, renders it easy to distinguish the shell of a brachiopod from that of a lamellibranch. In many forms the two valves are joined together by means of a hinge, these constitute the group *Articulata*; in others they are held together by muscles only, these form the *Inarticulata.* The hinge consists of two short curved processes or teeth given off from the ventral valve near the umbo, which fit into corresponding sockets in the dorsal valve. In some genera (*e.g. Orthis*) the teeth are supported by plates (the *dental plates*) which are fixed to the inside of the ventral valve. The line on which the two valves move in the opening and closing of the shell, is termed the *hinge-line* (fig. 63, *g—h*). In some genera (*Terebratula*) this is short and curved, in others (*Spirifer*, fig. 75) it is long and straight. The posterior part of the shell is that

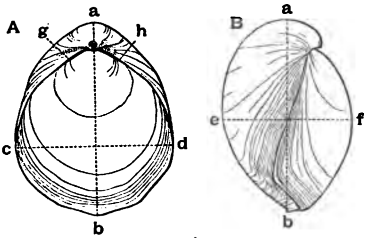

FIG. 63. *Terebratula semiglobosa*, Upper Chalk. *A*, dorsal view. *B*, lateral view. *a*, posterior; *b*, anterior; *a—b*, length; *c—d*, breadth; *e—f*, thickness; *g—h*, hinge-line. × $\frac{2}{3}$.

near the hinge (fig. 63, *a*), the anterior is the opposite margin (*b*). The length of the shell is measured from the anterior to the posterior border (*b*—*a*). The breadth is at right angles to this, from one side of the shell to the other (*c*—*d*). The thickness is measured from one valve to the other, perpendicular to the length and breadth (*e*—*f*). In some genera (*e.g. Terebratula*) the length is greater than the breadth, in others (*e.g. Strophomena*) the breadth is greater. Between the hinge-line and the umbo there is in some brachiopods (*e.g. Cyrtia*, fig. 64) a flat or slightly concave portion of the shell, usually triangular, on which the ornamentation of the rest of the shell is absent, the surface being either smooth or striated; this is known as the *area*. It may occur on both valves (*e.g. Orthis*), but is often found on the ventral valve only.

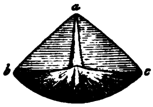

Fig. 64. *Cyrtia exporrecta*, Wenlock Limestone. *a*, umbo of ventral valve; *abc*, area; *b*—*c*, hinge-line. Natural size.

Nearly all living brachiopods are fixed to a rock or other object; but some fossil forms were free, especially in old age (*e.g. Productus*). Some, like *Crania*, are attached by one valve being soldered to the rock; others (*e.g. Strophalosia*) by spines given off from the surface of the shell. More commonly, however, the attachment takes place by means of a stalk or peduncle; this is a cylindrical process, in some genera long, in others short, connected with the mantle, and passing out either through an opening in the ventral valve (fig. 65 *A*, *f*) or between the umbones (*e.g. Lingula*, fig. 69). It is composed mainly of supporting-tissue with a sheath of horny material, but in some forms there are muscular layers also.

The opening for the passage of the peduncle varies considerably in different genera, and is a feature of importance in classification. The simplest case is that found in *Lingula* and some others, in which the opening is shared by both valves. In other types we find that the peduncle-opening is confined to the ventral valve; in *Discina* the opening is completely enclosed by the shell and is often near the centre of the valve; consequently the peduncle comes out at right angles to the plane of the valves. Sometimes, as in *Orthis* (fig. 73), the peduncle-opening is in the form of a triangular fissure, under the umbo, known as the *delthyrium*. In brachiopods belonging to the group Telotremata, a similar delthyrium is found in young individuals, but subsequently becomes partly closed by two plates, which grow inwards from the sides of the delthyrium and sometimes meet in the middle line. These two plates form the *deltidium*. In *Rhynchonella* the two plates meet, but a small circular or ovate opening (the *foramen*) is left near the centre for the peduncle. In *Magellania* (fig. 65 *A*) the foramen is quite at the apex of the umbo, its lower boundary being formed by the deltidium (*d*). In genera belonging to the Protremata and a few of the Neotremata, the delthyrium is more or less completely filled up by a shelly growth known as the *pseudo-deltidium*; this at first sight closely resembles the deltidium, but is really of a different nature. It is secreted by the peduncle and the dorsal surface of the mantle, although attached to the ventral valve, whereas the deltidium is formed by the edge of the ventral lobe and originally consists of a pair of plates. It is also developed at an earlier stage than the deltidium, and grows from the apex of the delthyrium downwards, becoming fused to the ventral valve.

The two valves of the brachiopod can be opened and closed by means of muscles (fig. 62); those which open them are called the *divaricators* (*c*, *c*′), those which close them, the *adductors* (*a*). When the soft parts of the animal have been removed the places where the muscles were attached to the interior of the shell are indicated by a difference in the surface such as striation, or by slight depressions or elevations; these markings are termed the *muscular impressions*. In the articulate brachiopods there are generally five or six pairs of muscles. In the genus *Magellania* there are two pairs of divaricators (fig. 62 *A*, *c*, *c*′) and one of adductors (*a*). Both pairs of the former are attached to a process (the *cardinal process*, fig. 65 *B*, *c*, *c*′) on the dorsal valve between the teeth sockets, and one pair join the ventral valve near its centre (fig. 65 *A*, *c*), while the other pair, which are smaller, are attached

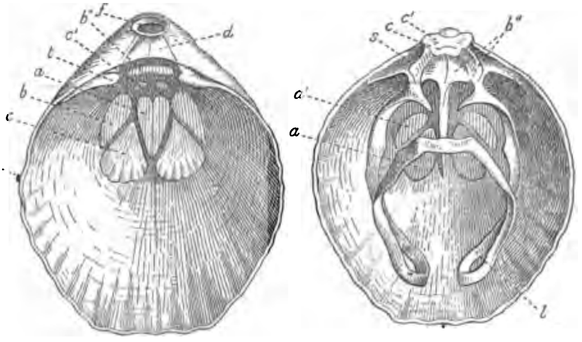

FIG. 65. *Magellania* [= *Waldheimia*] *flavescens*, Recent. *A*, Interior of ventral valve. *f*, foramen; *d*, deltidium; *t*, teeth; *a*, impressions of adductor muscles; *c*, *c*′, impressions of divaricator muscles; *b*, *b*″, muscles of the peduncle. *B*, Interior of dorsal valve. *c*, *c*′, cardinal process; *b*″, hinge-plate; *s*, dental sockets; *l*, loop; *a*, *a*′, adductor impressions; *c*, point of attachment of the smaller divaricator. (After Davidson.) × 1½.

nearer the posterior border (*c*′). Hence the dorsal valve forms with these two pairs of muscles a lever of the first order. The adductor muscles are united to the ventral valve near the centre (fig. 65 *A*, *a*) and form a single impression divided by a median line; these muscles bifurcate before reaching the dorsal valve and there form four impressions (fig. 65 *B*, *a*, *a*′). There are also muscles attached to the peduncle which serve to move the shell bodily, one pair of these being united to the dorsal valve (fig. 65 *B*, *b*″), the others to the ventral (*A*, *b*, *b*″). In the Inarticulata the muscles are much more complicated; thus, in *Lingula* (fig. 69) we find, in addition to the adductors and divaricators, muscles for moving one valve backward or forward in relation to the other, and others for giving a slight rotary motion.

The arms, already mentioned as occupying in most genera the main part of the mantle-cavity, are generally coiled up. In some forms they can be protruded a greater or shorter distance. Sometimes they are supported on a calcareous framework—the *brachial skeleton*—which is attached to the posterior part of the dorsal valve. In *Rhynchonella* (fig. 77 *B*, *c*) the brachial skeleton consists of two short curved processes. In *Terebratula* (fig. 79) there is a ribbon-like band forming a short loop. In *Stringocephalus* (fig. 81) the loop is more extensive and runs parallel to and near the margin of the valves. In *Magellania* (fig. 65 *B*) the loop extends nearly to the anterior margin of the shell and is then bent back upon itself. In other genera, the brachial skeleton is in the form of two spiral ribbons; in *Spirifer* (fig. 75 *A*) the apices of the spirals are directed towards the lateral margins of the shell, in *Glassia* they point inwards, in *Atrypa* (fig. 76 *A*) upwards to the centre of the dorsal surface. The brachial skeleton is absent in all the inarticulate genera, as well as in some of the articulate forms such as *Productus* and *Chonetes.*

The development of the brachial skeleton has been studied in some modern species of *Terebratulina, Magellania,* and *Terebratella.* In *Terebratulina* the adult form is reached almost directly; but in *Magellania* the brachial skeleton passes through various stages before the adult condition is attained; and it is noteworthy that these stages are similar to the adult forms of certain other genera. Thus in *Magellania venosa* the brachial skeleton passes through stages which, in succession, resemble the brachial skeletons of the genera *Gwynia, Cistella, Bouchardia, Megerlina, Magas, Magasella,* and *Terebratella,* after which the adult condition is reached. Another striking fact is that some species, which have hitherto been referred to the genus *Magellania,* have a development differing from this; thus *M. cranium* passes through stages distinctive of the genera *Gwynia, Cistella, Platidia, Ismenia, Mühlfeldtia,* and *Terebratella.* If the stages through which an individual passes in its development be taken to indicate its ancestry, then it follows that in *Magellania* there are two groups of species having different ancestors, and these two groups must therefore be regarded as constituting two distinct genera (see pages 13, 14).

The largest brachiopod known is *Productus giganteus,* from the Carboniferous Limestone, which has a breadth of twelve inches; the size of the shell in different genera varies from this down to about a quarter of an inch. Generally the shell is very thin, but in some forms (*e.g. Productus* (*Daviesiella*) *llangollensis*) it is thick and massive. The external form varies considerably; it may be globular, ovoid, hemispherical, quadrilateral, or triangular.

Usually both valves are convex, but in some genera, one is plane the other convex, or one may be concave and the other convex; in the last case the space in the interior is small. Sometimes there is a depression or sulcus on one valve (generally the ventral) and a corresponding ridge on the other valve. The surface of the shell is sometimes quite smooth, but is often punctate, or ornamented with striæ or ribs, which generally radiate from the umbones but are occasionally concentric. In a few forms the shell is covered with spines.

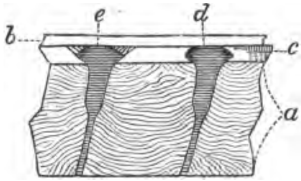

FIG. 66. Vertical section of shell of *Magellania* [= *Waldheimia*] *flavescens*, Recent. *a*, prismatic layer; *b*, chitinous layer; *c*, outer calcareous layer; *e*, *d*, canals traversing the calcareous layers. (After King.) Magnified.

In the Articulata the shell is mainly calcareous. In the genus *Magellania* it is formed of three layers (fig. 66); the inner (*a*), next the mantle, is the thickest and most important, and consists of flattened prisms of calcite arranged obliquely to the surface of the shell, each prism being encased in a membrane, which of course has disappeared in the fossil examples. The middle layer (*c*) is lamellated and also calcareous. The outer (*b*) consists of chitinous

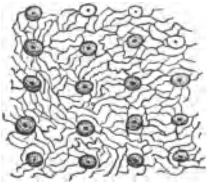

FIG. 67. Horizontal section through the prismatic layer of *Terebratula maxillata*, from the Great Oolite, showing prisms and canals. Magnified.

material. The inner and middle layers are traversed by canals (figs. 66, *e*, *d*, 67) running at right angles to the surface of the shell, and containing prolongations of the mantle. The shell is secreted by the mantle, its outermost border producing the chitinous layer, a zone just within this forming the lamellated layer, and the remainder giving rise to the prismatic layer which gradually encroaches on the preceding; hence the last layer is the only one which can subsequently increase in thickness. In many forms the lamellated layer is absent, and some (*e.g. Rhynchonella*) possess no canals traversing the calcareous layers.

The shell of the Inarticulata has a different structure. In *Lingula* it consists of alternating calcareous and chitinous layers, the calcareous material being mainly phosphate of lime. The canals which traverse these layers are more numerous and much smaller than those found in the articulate forms.

The different stages in the growth and decline of the brachiopod shell, from the embryo up to old age, have been carefully studied by Beecher. He finds that the shell in the earliest or embryonic stage is similar in character in all the genera which he has examined; he calls this embryonic shell the *protegulum*. Sometimes the protegulum may be found at the umbones of adult

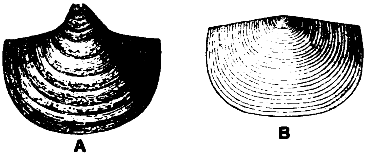

FIG. 68. *Iphidea* [=*Paterina*] *labradorica*, from the Lower Cambrian (Olenellus Beds). *A*, ventral valve. *B*, dorsal valve. Enlarged.

shells, but generally, owing to its delicate nature, it has been worn off; it is semicircular or semi-elliptical in form, and is marked with concentric lines of growth; its size varies from ·05 to ·60 millimetre. From the constancy of the occurrence of the protegulum it may be reasonably inferred that the ancestral form of the Brachiopoda possessed throughout life a shell similar to the protegulum. This view seems to be supported by the occurrence in the Lower Cambrian (*Olenellus* Beds) of North America of a brachiopod of this nature, named *Iphidea* (fig. 68).

The Brachiopoda are divided by nearly all authors into two groups—the *Inarticulata* and the *Articulata*[1]—the characters of which have already been described. Each of these groups may be divided into two Orders, based to a large extent on the character of the peduncle-opening (p. 157).

SUB-CLASS I. INARTICULATA.

The valves are not provided with teeth, but are held together by muscles only. The intestine is long and ends in an anus. There is no brachial skeleton.

ORDER I. ATREMATA.

The peduncle passes out between the umbones, the opening being shared by both valves. *E.g. Lingula.*

Obolella. Shell ovate or sub-circular, lenticular. Ventral valve with a thick umbo, and a small area with a groove in the middle; one pair of long muscular impressions extend from near the hinge-line to the middle of the valve, between these are a pair of small impressions, and near the hinge-line a third pair of small impressions. Dorsal valve with a minute umbo, and an internal median ridge. Cambrian. Ex. *O. polita.*

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[1] These have also received other names; the Inarticulata being known by some authors as the Lyopomata, the Ecardines, the Pleuropygia, or the Tretenterata; and the Articulata as the Arthropomata, the Testicardines, the Apygia, or the Clistenterata.

Lingula (fig. 69). Shell thin, nearly equivalve, compressed, elongate-ovate or quadrilateral, tapering towards the umbones, slightly gaping at the extremities. Dorsal valve a little shorter than the ventral. Hinge-line slightly thickened. Twelve muscular impressions in each valve, but only feebly marked. Surface of shell smooth, or concentrically or radially striated. Peduncle long, passing between the umbones. Shell composed mainly of alternating layers of phosphate of lime and chitinous material. Cambrian[1] to present day. Ex. *L. anatina*, Recent; *L. ovalis*, Kimeridge Clay.

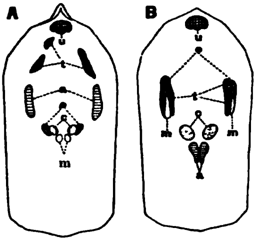

Fig. 69. *Lingula anatina*, Recent. Interior of valves showing muscular impressions. *A*, ventral valve. *B*, dorsal valve. *u*, umbonal muscle; *t*, transmedians; *c*, centrals; *a*, anterior laterals; *m*, middle laterals; *e*, external laterals. × ½.

Lingulella. Distinguished from *Lingula* by the presence, in the ventral valve, of a distinct slit and of a high hinge-area. Cambrian to Ordovician. Ex. *L. davisi*, Lingula Flags.

ORDER II. NEOTREMATA.

The peduncle-opening is confined to the ventral valve. In the lower types the opening is in the form of a slit at the margin of the valve; but in the higher forms it is completely surrounded by shell, and is often near the centre of the valve, in which case the peduncle passes out at right angles to the plane of junction of the two valves. *E.g. Discina.*

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[1] The internal characters of many of the species found in the Lower Palæozoic formations are only imperfectly known; it is therefore possible that these early forms may not belong to this genus.

Siphonotreta. Shell elongate-oval, biconvex, inequivalve, with spines on the surface. Hinge-line curved; no area. Ventral valve rather convex, with a prominent, straight umbo, having a foramen at its apex continued as a tube to the interior of the valve. Dorsal valve less convex, with umbo at the margin. Muscular impressions near the hinge-line in both valves. Ordovician and Silurian. Ex. *S. micula*, Llandeilo.

Discina (group). Shell sub-orbicular, or sub-elliptical, surface smooth or covered with striæ of growth. Valves more or less conical, the summits of both sub-central or sub-posterior. Animal attached by a peduncle passing through an opening in the ventral valve, which is placed either near the summit or a little behind it. Four adductor impressions. Cambrian to present day.

The definition of *Discina* given above includes the three genera *Discina* (restricted), *Discinisca*, and *Orbiculoidea*; in the Palæozoic specimens it is generally difficult, owing to imperfect preservation, to make out their distinguishing features; consequently it will often be convenient to use the term *Discina* in a wide sense. The characters of the three forms are:—

Discina (restricted). Both valves convex. Peduncle-opening small, externally near the middle of the valve, passing through the shell obliquely forwards. The only species definitely known is *D. striata*, Recent.

Discinisca. Ventral valve flattened; behind the apex is a disc, which is depressed externally and interrupts the continuity of the lines of growth. The disc is perforated for the peduncle by a fissure which passes directly, not obliquely, through it. Perhaps Tertiary or earlier. Ex. *D. lamellosa*, Recent.

Orbiculoidea. Ventral valve flattened; on the surface just behind the apex is a narrow furrow, which is perforated at the point farthest from the apex, the perforation passing through the shell obliquely backwards. Silurian to Carboniferous, perhaps also Mesozoic Ex. *O. morrisi*, Wenlock Limestone.

Crania (fig. 70). Shell calcareous, quadrangular or sub-circular, smooth or furnished with radiating ribs, fixed by the ventral valve; without peduncle-opening. Ventral valve depressed-conical; dorsal larger than the ventral, conical with a sub-central apex. Internal border of both valves covered with coarse granulations. Two pairs of well-marked adductor impressions in each valve (*aa'*); the posterior pair near the margin, the anterior near the centres of the valves and close together, especially so in the ventral valve. Also other smaller muscular impressions. Ordovician to present day. Ex. *C. ignabergensis*, Upper Chalk.

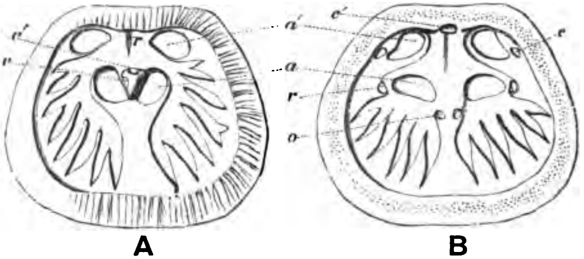

FIG. 70. *Crania anomala*, Recent. *A*, interior of ventral valve; *B*, dorsal valve. *a*, anterior adductors; *a'*, posterior adductors; *c*, posterior adjustors; *c'*, cardinal muscle; *r*, *o*, central and external adjustors. (From Woodward.) × 2.

SUB-CLASS II. ARTICULATA.

The valves articulate by means of two teeth on the ventral valve which fit into sockets on the dorsal. The intestine is short and ends blindly. A brachial skeleton may or may not be present.

ORDER I. PROTREMATA.

A pseudo-deltidium is developed, but may disappear in the adult. The peduncle-opening is at the margin of the valve, in the form of a fissure either opening at the hinge-line or more or less completely closed by the pseudodeltidium. *E.g. Orthis.*

Kutorgina. Shell calcareous, broader than long, with a long, straight hinge-line; surface with concentric striæ. Ventral valve very convex, with an elevated umbo; four pairs of muscular impressions. Dorsal valve flat or slightly convex, with two pairs of muscular impressions. Areas of both valves narrow, with a wide fissure. Cambrian. Ex. *K. cingulata.*

Productus (fig. 71). Shell free, generally transverse (*i.e.* broader than long) but sometimes elongated, often produced into

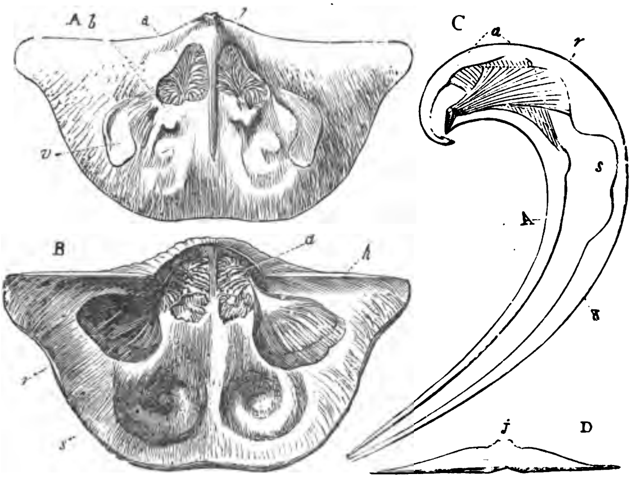

FIG. 71. *Productus giganteus*, Carboniferous Limestone. *A*, interior of dorsal valve; *B*, interior of ventral valve; *C*, ideal section of both valves; *D*, dorsal hinge-line. *j*, cardinal process; *a*, adductor; *r*, divaricator; *h*, ventral area; *b*, brachial prominence (?); *s*, hollows occupied by the spiral arms; *v*, reniform impressions. (From Woodward.) × ⅓.

ears in the umbonal region. Dorsal valve concave. Ventral valve very convex, often sharply bent, sometimes with a median sinus; umbo large, incurved, imperforate. Hinge-line straight, teeth absent or rudimentary. Area linear or absent. Surface ornamented with radiating ribs, crossed by concentric folds, especially in the umbonal region. Tubular spines, especially in the region of the umbo and ears. Muscular impressions strongly marked; in the ventral valve the adductors (*a*) are near the umbo, and in front of them the divaricators (*r*) are inserted. A prominent cardinal process (*j*) on the dorsal valve which is continued as a median ridge in the interior. No brachial skeleton. Devonian to Permian. Ex. *P. semireticulatus*, Carboniferous Limestone.

Strophalosia. Shell similar to *Productus* in form; attached by umbo of ventral valve. A well-marked area on each valve, with a pseudo-deltidium; the ventral area larger than the dorsal. Ventral valve with two prominent teeth. Dorsal valve with a prominent, bifid cardinal process. Surface of ventral (and sometimes also the dorsal) valve covered with spines. Devonian to Permian. Ex. *S. excavata*, Permian.

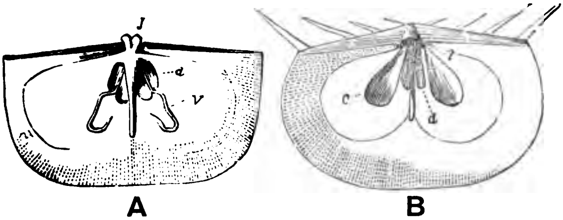

FIG. 72. *Chonetes* from the Devonian. *A*, dorsal; *B*, ventral valve. *a*, adductor impressions; *c*, divaricators; *t*, teeth; *v*, vascular impressions; *j*, cardinal process. (From Woodward.) Enlarged.

Chonetes (fig. 72). Shell transverse, semicircular, concavo-convex, or sometimes plano-convex. Hinge-line straight, forming the greatest width of the shell. Teeth strong. An area on each valve. Upper margin of area of ventral valve furnished with a row of hollow, diverging spines, which increase in length towards the terminations of the hinge-line. Peduncle-opening more or less completely closed by a pseudo-deltidium. Muscular impressions faintly marked. Surface ornamented with radial striæ. Silurian to Permian. Ex. *C. striatella*, Upper Ludlow.

Leptæna. Shell concavo-convex, semicircular or nearly quadrangular, ornamented with small radiating ribs, crossed by concentric folds on the flatter parts; anterior part bent sharply, often at a right angle. Space between the two valves very small. Hinge-line straight, forming the greatest width of the shell. An area on each valve, that of the dorsal valve linear, that of the ventral valve larger and with a median notch covered by a pseudo-deltidium. Umbo of ventral valve perforated by a small circular foramen except in old age. Two strong diverging teeth in the ventral valve. Muscular impressions—in the ventral valve, two narrow adductors surrounded by two large divaricators; in the dorsal, two small adductors near the centre of the valve, behind which are two larger adductors. Ordovician to Carboniferous. Ex. *L. rhomboidalis*, Bala Beds, etc.

Strophomena. Shell concavo-convex, semicircular or semi-elliptical, ornamented with radiating ribs. Hinge-line straight, forming the greatest width; a pseudo-deltidium is present. Ventral area conspicuous, the dorsal narrow. Teeth diverging widely, supported by plates, which are produced into ridges nearly surrounding the muscular area; the latter is divided by a median ridge. Dorsal valve with a ridge separating two large adductor impressions, in front of which are two narrow impressions. Ordovician and Silurian. Ex. *S. antiquata*, Wenlock Limestone.

Orthis (fig. 73)[1]. Outline sub-circular or quadrate. Both

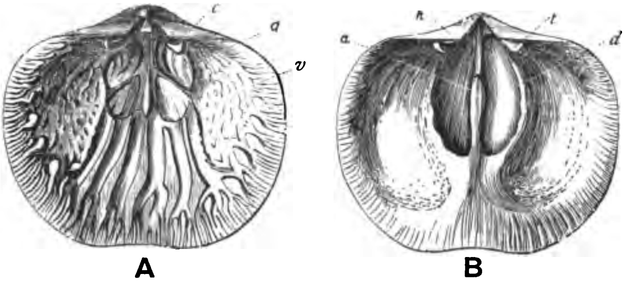

FIG. 73. *Orthis striatula*, Devonian. *A*, interior of dorsal valve; *B*, ventral valve. *c*, curved brachial processes (crura); *v*, genital impressions; *h*, area; *t*, teeth; *a*, adductors; *d*, divaricators. (From Woodward.) Natural size.

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[1] A large number of species showing considerable differences have been placed in this genus, and according to the work of recent authors it must be regarded as a group including several different genera.

valves convex. Surface radially ribbed or striated. Hinge-line straight, sometimes equal to the width of the shell, but generally shorter. An area on either valve, each divided by a median triangular fissure (delthyrium). In the ventral valve two large teeth, supported by dental plates. Four muscular impressions in the dorsal valve. Two long, narrow impressions (*d*) with two smaller ones (*a*) between them in the ventral. Cambrian to Carboniferous. Ex. *O. calligramma*, Ordovician and lower part of Silurian; *O. flabellulum*, Bala Beds; *O. resupinata*, Carboniferous Limestone.

Pentamerus (fig. 74). Shell oval, ornamented with ribs, rarely smooth. Ventral valve the more convex. Dorsal valve usually with a fold in front, ventral valve with a corresponding depression. Umbo of ventral valve sharp, strongly incurved, usually touching the dorsal valve and concealing the triangular aperture. No area; usually no pseudo-deltidium. Dental-plates (*d*) trough-like, converging in the ventral valve to form a median septum (*s*); in the dorsal valve two septa close together (*ss*). Silurian to Devonian. Ex. *P. oblongus*, Llandovery; *P. knighti*, Aymestry Limestone; *P. galeatus*, Wenlock Limestone. *Conchidium* and *Gypidula* are sub-genera of *Pentamerus* as defined above, but by some writers they are regarded as independent genera.

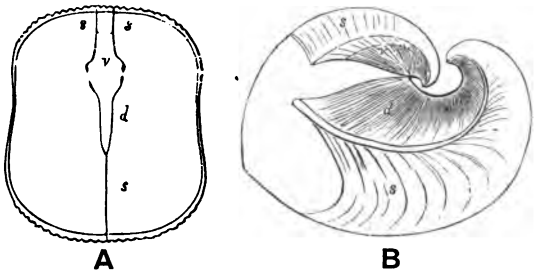

Fig. 74. *Pentamerus* (*Conchidium*) *knighti*, Aymestry Limestone. *A*, transverse section; *B*, longitudinal section. *ss*, dorsal septa; *s*, ventral septum; *d*, dental plates. (From Woodward.) × ½.

Stricklandia. Shell large, oval, ornamented with ribs; valves nearly equal, sometimes with a fold and a sinus. An area on the ventral valve. A short median septum in the ventral valve from which arise two plates forming a small chamber under the umbo. Silurian. Ex. *S. lens*, Llandovery Beds.

ORDER II. TELOTREMATA.

The peduncle-opening is confined to the ventral valve, and is placed either at the umbo or beneath it. A deltidium is developed. *E.g. Magellania.*

Spirifer (fig. 75). Shell transverse, more or less triangular, biconvex, smooth or ornamented with ribs or striæ. Often with a sinus on the ventral valve and a ridge on the dorsal. Hinge-line long and straight. An area on each valve, the ventral one triangular, often transversely striated, divided by a median triangular slit, which is partly closed by a deltidium; dorsal area small, also with a median slit. Teeth supported by dental plates. Brachial skeleton often filling a great part of the interior of the shell, in the form of two spiral ribbons, with their apices directed laterally. Silurian to Permian. Ex. *S. striatus*, Carboniferous Limestone.

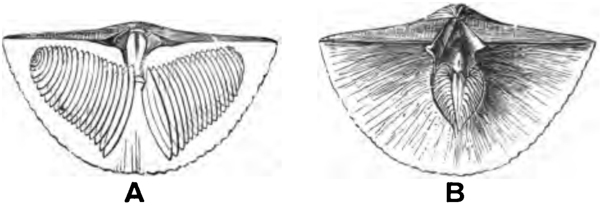

FIG. 75. *Spirifer striatus*, Carboniferous. *A*, interior of dorsal valve, showing brachial skeleton. *B*, interior of ventral valve, showing muscular impressions and area. (From Woodward.) × ½.

The sub-genus *Spiriferina* possesses a high median septum in the ventral valve. Devonian to Lias. Ex. *S. walcotti*, Lias.

Cyrtia (fig. 64). Area on the ventral valve very large, with a convex deltidium. Dental plates well developed but not joining. Brachial skeleton as in *Spirifer*, but the apices of the spires are nearer the hinge-line. Silurian (? Devonian). Ex. *C. exporrecta*, Wenlock Limestone.

Uncites. Shell elongate-oval, biconvex, striated. Hinge-line curved, no area. Umbo of the ventral valve prominent and incurved, foramen closed in the adult; deltidium concave. Dental plates strong. Apex of dorsal valve incurved and partly hidden in the ventral valve, cardinal process prominent. Brachial skeleton spiral, the apices of the spires directed laterally. Devonian. Ex. *U. gryphus.*

Athyris. Shell biconvex, with transversely elliptical or sub-circular outline, and a median sinus. Surface often with concentric growth-lines produced into lamellæ. Hinge-line curved. Ventral umbo small, incurved, usually concealing the foramen and deltidium; with prominent teeth supported by dental plates; four muscular impressions. Dorsal valve with a tube from the interior of the valve opening at the hinge. Brachial skeleton consisting of two spires joined by a band; the apices of the spires pointing laterally. Devonian and Carboniferous. Ex. *A. concentrica*, Devonian.

Atrypa (fig. 76). Shell sub-circular, biconvex, ornamented with radiating ribs, often crossed by well-marked lines of growth. Ventral valve depressed in front; dorsal valve often much inflated. Hinge-line curved; no area. A small circular foramen, and a small deltidium.

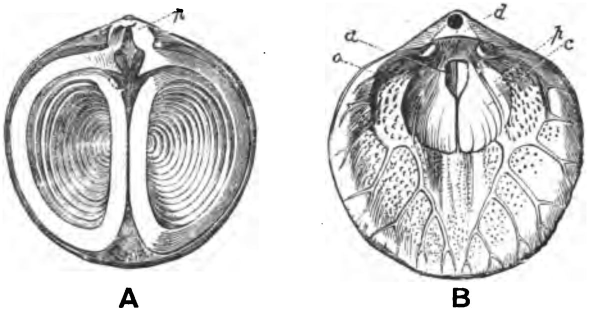

Fig. 76. *Atrypa reticularis*, Wenlock Limestone. *A*, dorsal valve showing brachial skeleton. *B*, interior of ventral valve. *a*, impressions of adductor muscles; *c*, divaricator muscles; *p*, muscles of peduncle; *o*, genital impression; *d*, deltidium. (From Woodward.) Natural size.

Ventral valve with two strong crenulate teeth; muscular impressions grouped at the centre of the valve. Brachial skeleton in the form of two spirals with their apices directed toward the centre of the dorsal valve; the two spires joined by a band near the umbo. Ordovician to Trias. Ex. *A. reticularis*, Wenlock Limestone.

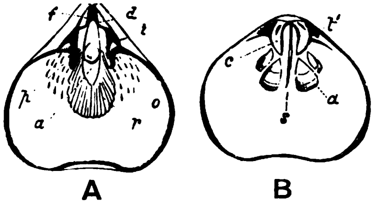

FIG. 77. *Rhynchonella* (*Hemithyris*) *psittacea*, Recent. *A*, interior of ventral; *B*, interior of dorsal valve. *f*, foramen; *d*, deltidium; *t*, teeth; *a*, adductor impressions; *r*, divaricator impressions; *p*, peduncular impressions; *o*, genital impressions; *t'*, dental sockets; *c*, brachial skeleton; *s*, septum. (From Woodward.) Natural size.

Rhynchonella (figs. 77, 78). Shell triangular, elongated or rounded, very convex, not perforated by canals, usually ornamented with radiating ribs. Usually a sinus on the ventral valve and a

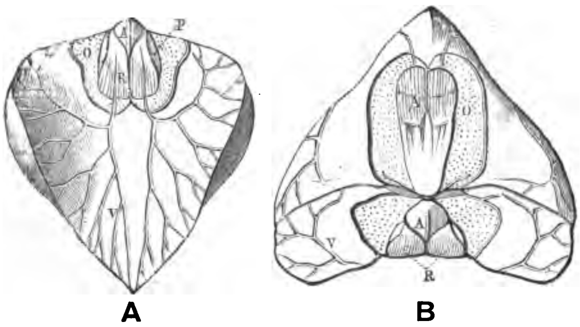

FIG. 78. *Rhynchonella* (*Pugnax*) *acuminata*, Carboniferous Limestone. Internal casts. *A*, Ventral valve. *B*, Dorsal valve and posterior part of ventral. V, 'vascular' impressions; O, genital impressions; A, adductors; R, divaricators; P, muscles of the peduncle. (From Woodward.) Natural size.

corresponding ridge on the dorsal. Umbo small, acute, incurved; foramen usually enclosed by the deltidium. Ventral valve with two strong teeth, muscular impression in middle of valve. Brachial skeleton reduced to two short, free, curved lamellæ. Ordovician[1] to present day. Ex. *R. cynocephala* and *R.* (*Acanthothyris*) *spinosa*, Inferior Oolite; *R. plicatilis*, Upper Chalk; *R. psittacea*, Pliocene and Recent. *Acanthothyris* is a sub-genus, including forms which have the shell covered with spines; chiefly Jurassic.

Terebratula (figs. 63, 79). Shell biconvex; oval, elongate, or rounded; surface nearly always smooth; often with two folds on the dorsal valve and two corresponding sinuses on the ventral. Hinge-line curved. Umbo of ventral valve truncated by a circular foramen, having a deltidium at its base. Brachial skeleton in the form of a short loop extending only about a third the length of the shell. Jurassic to present day. Ex. *T. maxillata*, Inferior and Great Oolite.

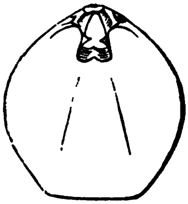

FIG. 79. *Terebratula* (*Liothyris*) *vitrea*, Recent. Interior of dorsal valve, showing the brachial skeleton. (From Woodward.) × $\frac{2}{3}$.

Dielasma (Devonian to Permian) and *Cænothyris* (Trias) are distinguished from the *Terebratulæ* of Jurassic and later formations mainly by the possession of well-developed dental plates. Ex. *Dielasma hastatum*, Carboniferous; *Cænothyris vulgaris*, Trias.

Magellania (= *Waldheimia*) (fig. 65). Distinguished from *Terebratula* by the longer brachial loop, extending to at least half the length of the shell, and by a median septum in the dorsal valve, which is, however, sometimes rudimentary. The shell may be smooth, or with folds, or radially ribbed. Lias to present day. Ex. *M. flavescens*, Recent; *M. cornuta*, Lias; *M. impressa*, Oxford Clay.

Magellania, as defined above, includes a large number of species which have been divided into several groups; by some authors these divisions are regarded as genera or sub-genera, some of the more important being:—*Eudesia* (ex. *E. cardium*, Great Oolite); *Zeilleria* (ex. *Z. cornuta*, Lias); *Microthyris* (ex. *M. lagenalis*, Cornbrash).

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[1] The Palæozoic species differ in several respects from the later ones and are regarded by some authors as belonging to other genera.

Terebratulina (fig. 80). Form similar to *Terebratula*. Ornamented with fine radiating ribs. Umbo short, foramen large, deltidium small. Two ear-like processes at the sides of the dorsal umbo. Brachial loop short, with a ring formed by a band between the two branches. Jurassic to present day. Ex. *T. striata*, Chalk.

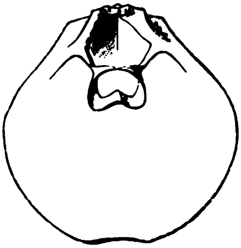

FIG. 80. *Terebratulina caput-serpentis*. Interior of dorsal valve. Recent. (From Woodward.) ×2.

Stringocephalus (fig. 81). Shell smooth, nearly circular in outline. Ventral valve with a sharp prominent umbo; area present. Foramen large in young individuals, but smaller and oval in the adult on account of the development of the deltidium. Teeth large. Ventral valve with a median septum

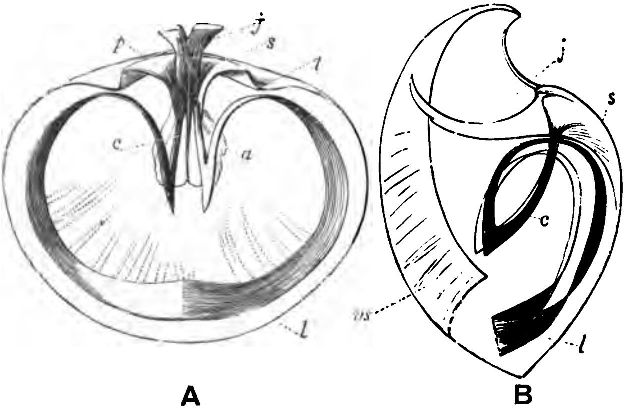

FIG. 81. *Stringocephalus burtini*, Devonian. *A*, Dorsal valve. *B*, Profile. *a*, adductor; *c*, crura; *l*, loop; *j*, cardinal process; *p*, hinge-plate; *s*, dorsal septum; *vs*, ventral septum; *t*, dental sockets. (From Woodward.) ×½.

(*vs*), which extends from the umbo almost to the front of the valve, and increases in height towards the latter. Dorsal valve less convex, with a small septum (*s*), and a long slightly curved cardinal process (*j*), divided at its extremity to embrace the ventral septum. The brachial skeleton consists of two branches arising from the hinge-plate (*p*), which pass to the middle of the shell (*c*) and are then sharply bent back and form a ribbon (*l*) parallel to the margin of the valve. Devonian. Ex. *S. burtini.*

Distribution of the Brachiopoda.

The Brachiopods are all marine, and are found in all parts of the world; at the present time they are much less numerous than in former periods of the earth's history, there being only about 120 living species. Many forms occur more abundantly where the sea-bottom is rocky, or stony, or formed of corals, than where it is soft or muddy; frequently they are much localised, being found in enormous numbers at one spot, whilst, in the adjoining areas, they are sparsely distributed. About half of the existing species are found at depths of less than 100 fathoms, and several of these do not extend beyond this limit. Below 150 fathoms they soon become comparatively rare, but a few species (*e.g. Terebratulina wyvillei*) occur down to 2900 fathoms. Some genera, as for instance *Lingula,* do not occur below a depth of a few fathoms. In the Littoral zone (see p. 238) Brachiopods are less numerous than elsewhere, only 17 species occurring in it. The Laminarian zone contains 46 species, of which 15 (including 5 species of *Lingula*) are confined to it. In the zone of Nullipores there are rather fewer forms than in the preceding one. The zone of Brachiopods and Corals is, as its name suggests, the richest in Brachiopods, containing no less than 58 species or varieties. In the Abyssal zone 30 species have been dredged, but the greater number come from the upper part of the zone; the Inarticulata are poorly represented here. Geographically, the Brachiopoda which live in comparatively shallow water are distributed in provinces, agreeing generally with the Molluscan provinces (p. 237). These are characterised by the presence or abundance of certain species, and are determined mainly by climate. With one or two exceptions all the species found in the Northern Hemisphere are distinct from those in the Southern. Amongst the forms limited to the cold northern regions may be mentioned *Rhynchonella psittacea* and *Magellania septigera,* whilst *R. nigricans* and *M. venosa* are found only in cold southern regions. A few species, as for example *Terebratulina caput-serpentis,* have a very wide geographical distribution, extending from polar to tropical regions, and also have a great range in depth, the form mentioned being found from the shore-line down to 1180 fathoms.

The species confined to shallow water have generally a much more limited geographical range than those found in deeper water; and the polar or boreal species have a wider range than the tropical, since they can find the same temperature in lower latitudes at greater depths.

The Brachiopods are very abundant as fossils, especially in the Palæozoic formations. The earliest forms occur in the Lower Cambrian (*Olenellus* Beds); it is remarkable that in this division in North America no less than thirteen genera are represented, of which *Lingulella, Iphidea, Kutorgina, Obolella,* and *Orthis* may be mentioned. In the Ordovician System the Brachiopods are much more numerous than in the Cambrian, and they attain their maximum in the Silurian; their decline begins with the Devonian and becomes especially marked in the Mesozoic period.

The chief genera met with in the different systems are:—

Cambrian. *Lingula*, *Lingulella*, *Kutorgina*, *Obolella*, '*Discina*,' and *Orthis*.

Ordovician. *Lingula*, *Orthis*, *Strophomena*, and *Leptæna*.

Silurian. *Lingula*, *Orbiculoidea*, *Atrypa*, *Orthis*, *Meristina*, *Spirifer*, *Rhynchonella*[1], *Pentamerus*, *Leptæna*, *Strophomena*, and *Chonetes*.

Devonian. *Uncites*, *Stringocephalus*, *Atrypa*, *Orthis*, and *Spirifer*.

Carboniferous. *Lingula*, *Orbiculoidea*, *Chonetes*, *Athyris*, *Orthis*, *Spirifer*, *Productus*, *Dielasma*, and *Rhynchonella*[1]. *Spirifer* and *Productus* are particularly abundant.

Permian. *Productus*, *Strophalosia*, *Spirifer*, and *Rhynchonella*.

Mesozoic. Most of the important Palæozoic genera die out before the commencement of the Mesozoic. This period is remarkable for the extraordinary abundance of *Terebratula*, *Magellania*, and *Rhynchonella*. Other genera which occur are *Lingula*, *Crania*, *Thecidium*, *Terebratulina*, and *Terebratella*—the last two are common in the Cretaceous, where *Magas* and *Kingena* also occur. *Koninckina* is confined to the Trias. *Spiriferina* is found in the Trias and Lias.

Tertiary. Brachiopods are very poorly represented; the following forms occur, but are not common:—*Lingula*, *Terebratula*, *Terebratulina*, and *Magellania*—all of these have living representatives. Other living forms are *Megathyris* (=*Argiope*), *Thecidium*, *Crania*, *Discina*, *Discinisca*, etc.

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[1] See note on p. 174.

PHYLUM POLYZOA[1].

Sub-Classes.	*Orders.*	*Sub-Orders.*
1. Ectoprocta.	1. Phylactolæma.	
	2. Gymnolæma....	1. Cyclostomata.
		2. Cheilostomata.
		3. Ctenostomata.
2. Entoprocta.		

WITH the exception of the genus *Loxosoma* all the Polyzoa are colonial animals, numerous individuals living in association. The colony is nearly always fixed, and may be arborescent, laminar, almost massive, or encrusting shells, stones, or plants. The entire colony is known as the *zoarium*; each individual (fig. 82 *A*) has a sac-like form; at the upper end there is a platform or disc, the *lophophore,* on which tentacles (*t*) are placed, arranged either in a circle or in the form of a horse-shoe. In most forms the tentacles are not contractile, but are provided with cilia, which produce a current of water that conveys food to the mouth (*o*). The anal aperture (*a*) is near the mouth, generally below the lophophore, but in some forms within the circle of tentacles. On account of this approximation of the mouth and anus the alimentary canal is bent into a U-shape; in it may be distinguished œsophagus (*œs*), stomach (*st*), and intestine (*int*). Between the alimentary canal and the body-wall is a spacious body-cavity. The nervous system consists of a single ganglion (*g*) placed

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[1] The name *Bryozoa* is used for this class by many authors.

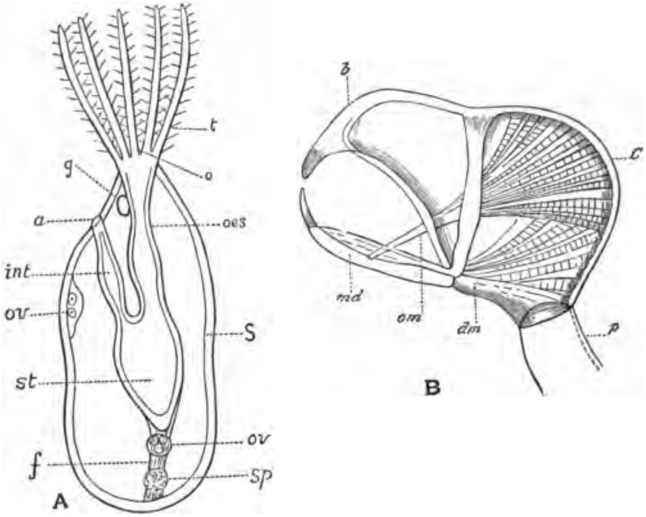

Fig. 82. *A*, Diagram of the structure of a single Polyzoan individual. *s*, body-wall; *t*, tentacles; *o*, mouth; *œs*, œsophagus; *st*, stomach; *int*, intestine; *a*, anus; *g*, ganglion; *f*, funiculus; *ov*, ovary; *sp*, testis. *B*, Avicularium of *Bugula*, enlarged. *b*, beak; *md*, mandible; *C*, chamber; *p*, peduncle; *om*, occlusor muscles; *dm*, divaricator muscles. (After Hincks, Brit. Mar. Polyzoa.)

on the side of the œsophagus facing the intestine. The polyzoa multiply by budding and sexually, and are generally hermaphrodite. Heart and blood-vessels are absent.

The structures described above form together what is known as the *polypide*; this is contained in the body-wall or *zoœcium*. The outer layer of the zoœcium, known as the *ectocyst*, generally becomes hardened by calcareous or chitinous matter, and after the death of the animal this alone remains; its surface is usually ornamented with ribs, etc. The anterior part of the polypide can be withdrawn by means of longitudinal muscles into the zoœcium, just as the finger of a glove can be pulled into the hand. In some Polyzoa (the Cyclostomata, fig. 83 *B*) the zoœcium is tube-like, the aperture is at the end and is of the same diameter, or nearly so, as the rest of the tube. In others (the Cheilostomata, fig. 83 *A*) the zoœcium is more or less oval, the aperture (*m*) is contracted and is not terminal, but is situated in front near the anterior end, and is provided with a movable lid or operculum. In many of the Cheilostomata there is at the anterior end of the zoœcium, above the aperture, a projecting chamber (*o*), termed the *oœcium,* into which the ova pass. In many forms of Cheilostomata some of the individuals are modified so as to form appendages termed *avicularia* and *vibracula,* but these are rarely preserved fossil. The avicularium (fig. 82 *B*) may be sessile or placed on a peduncle (*p*), and in the more specialized forms has somewhat the appearance of a bird's head, consisting of a chamber (*C*) produced into a beak and provided with

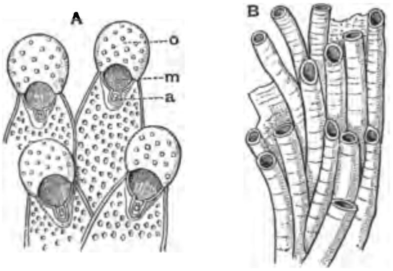

Fig. 83. *A*, **Portion of** ***Smittia landsborovi*****, a Cheilostomatous Polyzoan, Recent.** *o*, **oœcium;** *m*, **aperture of the cell;** *a*, **avicularium.** *B*, **Portion of** ***Tubulipora fimbria*****, a Cyclostomatous Polyzoan, Recent. Enlarged.**

a mandible (*md*) which is kept constantly snapping by means of muscles in the chamber. The vibraculum consists of a long seta kept in motion by means of muscles at its base. The individuals of a colony may communicate with one another, either directly, or by means of *communication-plates*; these are portions of the zoœcium which are thinner and perforated. The surface of the zoœcium may be smooth or punctate, or ornamented with spines, granules, or ribs.

The Polyzoa are divided into two sub-classes, (1) Ectoprocta, (2) Entoprocta. The Ectoprocta only are found fossil.

SUB-CLASS I. ECTOPROCTA.

The anal aperture is not situated within the area of the lophophore. There are two orders, (1) Phylactolæma, (2) Gymnolæma.

ORDER I. PHYLACTOLÆMA.

The lophophore is horse-shoe shaped. There is a tongue-shaped lip in front of the mouth, known as the epistome. The forms included in this order are found only in fresh-water and do not occur fossil.

ORDER II. GYMNOLÆMA.

The lophophore is circular, and there is no epistome. There are three sub-orders, (1) Cyclostomata, (2) Cheilostomata, (3) Ctenostomata. The last is not known in the fossil state.

SUB-ORDER I. CYCLOSTOMATA.

The zoœcia are calcareous and tubular, their apertures are round and terminal, not constricted and not provided with opercula. Vibracula are absent, and generally also avicularia and oœcia.

Berenicea. Zoarium a thin, flat, encrusting sheet—discoid, fan-shaped, or irregular. Zoœcia simple, tubular, arranged in irregularly alternating lines. Ordovician to present day—common in the Jurassic and Cretaceous. Ex. *B. diluviana*, Lias to Oxfordian.

Diastopora. Similar to *Berenicea*, but with erect, leaf-like zoarium, which may be simple or divided, or convoluted. Chiefly Jurassic and Cretaceous. Ex. *D. foliacea*, Bajocian and Bathonian.

Haplocœcia. Zoarium erect, dendroid; branches consisting of solid bundles of zoœcia, which are short and angular in form, with small orifices arranged either lineally or quincuncially. Jurassic. Ex. *H. straminea*, Bathonian.

Fenestella. Zoarium funnel-shaped or fan-shaped. Branches straight, united by cross-bars, so as to form a network. The cross-bars do not bear zoœcia. On each branch there is a median ridge or carina, on the sides of which the zoœcia occur. Openings of zoœcia round. Ordovician to Permian. Ex. *F. plebeia*, Carboniferous.

Theonoa (=*Fascicularia*). Zoarium large, generally massive and globose. Zoœcia in the form of long tubes, with horizontal tabulæ, in contact laterally, and forming bundles which are either distinct and radiate from the base to the periphery, or fuse into laminæ which intersect. Jurassic to Pliocene. Ex. *T. aurantium*. Coralline Crag.

SUB-ORDER II. CHEILOSTOMATA.

The zoœcia are calcareous and more or less oval, never tubular; their apertures are contracted and provided with a movable operculum. Avicularia, vibracula, and oœcia are often present.

Lunulites. Zoarium free, circular, the upper (celluliferous) surface convex, the lower surface concave or flat. Zoœcia arranged in radiating series, between which are small, elongate, vibracular cells.

Zoœcia with elevated borders; orifices round or semi-elliptical. Cretaceous to present day. Ex. *L. goldfussi*, Chalk.

Membranipora. Zoarium encrusting, generally irregular in form. Zoœcia quincuncial, or arranged irregularly, their margins raised, the anterior part depressed and more or less membranous. Chalk to present day. Ex. *M. bidens*, Coralline Crag.

A third sub-order of the Gymnolæma, named Trepostomata, has been introduced by Ulrich to include Palæozoic forms (*Monticulipora, Heterotrypa, Callopora, Batostoma,* etc.), which by some writers are regarded as Alcyonaria (see p. 91). A few Jurassic forms have also been referred to this sub-order by Gregory. The zoarium in the Trepostomata consists of sheets or masses formed of prismatic or cylindrical zoœcia placed parallel to one another and divided by diaphragms. The zoœcia may be in contact with one another or separated by smaller cells or vesicles.

Distribution of the Polyzoa.

By far the larger number of the Polyzoa are marine; they occur both in shallow and deep water. The deep-water forms belong mainly to the Cheilostomata; a few Ctenostomata occur at considerable depths, but the group is characteristic of shallow water. The Cyclostomata are comparatively rare at the present day, except in the Northern seas.

The earliest Polyzoa occur in the Ordovician rocks. Nearly all the Palæozoic genera are extinct; they belong mainly to the Cyclostomata. A few Cheilostomata have been recorded from the Jurassic rocks, but the group does not become abundant until the Cretaceous period; in the Tertiary it is better represented than the Cyclostomata. Very many of the Pliocene forms belong to species which are still living.

The chief genera found in the Palæozoic rocks are *Archimedes, Fenestella, Hemitrypa, Pinnatopora, Polypora, Ptilodictya,* and *Thamniscus*; in the Jurassic, *Berenicea, Diastopora, Entalophora, Haploœcia, Idmonea, Proboscina, Spiropora,* and *Stomatopora*; in the Cretaceous, *Ceriopora, Crisina, Diastopora, Heteropora, Lunulites, Membranipora, Proboscina, Spiropora,* and *Stomatopora*; in the Eocene, *Hornera, Idmonea,* and *Membranipora*; in the Pliocene, *Cellepora, Hornera, Lepralia, Membranipora, Onychocella,* and *Theonoa.*

PHYLUM MOLLUSCA.

Classes.	*Sub-Classes.*	*Orders*
1. Lamellibranchia.		
2. Gasteropoda	1. Isopleura.	
	2. Anisopleura	1. Streptoneura (Prosobranchia).
		2. Euthyneura.
3. Scaphopoda.		
	Orders.	*Sub-Orders.*
4. Cephalopoda	1. Tetrabranchia	1. Nautiloidea.
		2. Ammonoidea.
	2. Dibranchia	1. Decapoda.
		2. Octopoda.

THE majority of the molluscs (oysters, whelks, cuttlefish, etc.) are marine, but some live on land, others in fresh-water. Unlike the worms and arthropods, they are unsegmented animals, and they bear no serially repeated appendages. Typically the body is bilaterally symmetrical, and there is consequently a repetition of the same organs on each side; but in most gasteropods this symmetry is more or less completely lost. From the dorsal surface there is a fold of the skin forming what is known as the *mantle*; this generally secretes a calcareous shell, consisting of one or two (occasionally more) pieces. On the ventral surface of the body is the *foot*—a muscular organ used in locomotion. In most cases respiration takes place by means of gills, which are placed in the cavity enclosed by the mantle. A heart is present, and is placed on the dorsal surface; it consists usually of a ventricle and two auricles. The mouth is situated anteriorly, and, except in the lamellibranchs, is provided with a rasping organ, the *odontophore*; the anus, in typical forms, is placed posteriorly. Renal organs (nephridia) are present and place a part of the body-cavity in communication with the exterior. The nervous system consists of a ring round the œsophagus, and usually of three main groups of ganglia, from which nerves are given off. Sexual reproduction only occurs; most forms are unisexual, a few hermaphrodite.

The Mollusca are divided into four classes:—(1) Lamellibranchia, (2) Gasteropoda, (3) Scaphopoda, (4) Cephalopoda.

CLASS I. LAMELLIBRANCHIA.

In the lamellibranch, as in the brachiopod, the shell is generally calcareous and consists of two valves, but these instead of being dorsal and ventral as in the latter, are placed one on the right, the other on the left side of the body, and the two are joined together by means of a hinge and a ligament at the dorsal margin. The interior of the shell is lined by a fold of the skin, the *mantle* (fig. 84, *m*), which is divided into two lobes, one being placed in each valve. In the middle of the space enclosed by the mantle (the mantle-cavity) is the foot (*f*). This is a laterally flattened muscular organ, frequently hatchet-[1] or ploughshare-shaped, and is used for crawling, or for burrowing in sand or mud. Sometimes, as in the case of *Trigonia,* by means of a rapid movement, it enables the

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[1] Hence the name *Pelecypoda* used by some authors for this class.

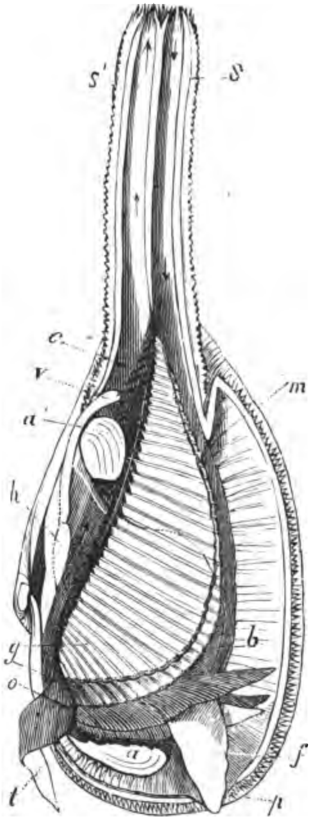

Fig. 84. *Mya arenaria.* The left valve and mantle and half the siphons have been removed. *a*, anterior adductor muscle; *a'*, posterior adductor; *b*, visceral mass; *c*, cloacal chamber into which the anus opens; *f*, foot; *g*, branchiæ; *h*, heart; *m*, cut edge of the mantle; *o*, mouth; *p*, edge of mantle; *s*, branchial siphon; *s'*, anal siphon; *t*, labial palps; *v*, anus. (From Woodward.)

animal to jump to a considerable distance. In the genus *Mytilus* the foot is very much reduced; in others which have lost the power of locomotion (*e.g. Ostrea*) it is absent altogether. On the posterior part of the foot there is in some genera (*e.g. Mytilus, Avicula, Arca*) a gland which secretes a bundle of horny fibres, known as the *byssus*, by means of which the animal moors itself to foreign objects. On each side of the foot, between it and the mantle, and attached to the body dorsally, are the gills or branchiæ (fig. 84, *g*); these consist of filaments which usually become connected so as to form leaf- or plate-like bodies, whence the name Lamellibranchia.

In some forms, the margins of the two mantle-lobes although in contact are not united, and when this is the case there are usually at the posterior margin two openings leading from the exterior to the mantle-cavity; these are produced by adjoining excavations or notches in the two lobes of the mantle. A current of water, caused by the cilia on the gills and mantle, flows in through the ventral opening, and provides the animal with food and oxygen; another current flows out through the dorsal opening, carrying with it fæcal matters. In many cases, however, the two lobes of the mantle are fused at one or more points; this union occurs between the exhalent and inhalent openings, and also, in many forms, below the latter opening. In this way the mantle becomes a kind of bag, having three openings, a ventral for the protrusion of the foot, and two posterior for the inhalent and exhalent currents of water. Frequently, at the posterior openings, the mantle is greatly produced so as to form two complete tubes, known as *siphons* (fig. 84, *s*, *s′*); these are sometimes free, sometimes united, and may be as much as four times the length of the shell. The ventral is generally the longer; it is furnished with tactile papillæ, and is known as the *branchial siphon* (*s*), the dorsal being the *anal siphon* (*s'*). In many forms the siphons can be withdrawn into the shell by means of muscles. Occasionally, as in *Teredo,* the siphons are surrounded by a calcareous tube.

The two valves of the shell can be closed by means of the adductor muscles (*a*, *a'*), which pass from the interior of one valve to the other. In many genera there are two adductors, and these forms are frequently spoken of as the *Dimyaria*; others, known as the *Monomyaria,* possess one adductor only, and when this is the case it is the posterior which is present, the anterior having atrophied; this occurs in the oyster, but in this, and in all other forms so far as is known, the anterior muscle is present in the young state.

In the lamellibranchs there is no head, hence the class is sometimes spoken of as the *Acephala.* The mouth (*o*) is placed in the middle line of the body, ventral to the anterior adductor muscle, and is not provided with organs of mastication. At each side are two leaf-like processes, the *labial palps* (*t*). The mouth leads into a short œsophagus, which passes into a globular stomach surrounded by the liver; next is the intestine, which, after undergoing many convolutions, reaches the dorsal surface of the body, where it passes through the pericardium and is surrounded by the ventricle of the heart. The anus (*v*) is situated dorsally to the posterior adductor muscle. The nervous system usually consists of three pairs of ganglia. One pair is placed at the sides of the mouth and is connected by nerve-cords with a pair in the foot, and with a third pair placed beneath the posterior adductor muscle. From these ganglia nerves are given off to the muscles, gills, etc. Tactile organs are present on the margin of the mantle and especially on the ventral siphon. In some forms eyes occur at the ventral margin of the mantle-lobes; they are especially well-developed in the genus *Pecten.* The heart (*h*) is placed dorsally, just below the hinge, and is surrounded by a large pericardial cavity; it consists of two auricles, and a ventricle, which, as already mentioned, extends round the intestine. The renal organs consist of a pair of glandular tubes underneath the pericardium. In almost all cases the sexes are separate, but a few forms are hermaphrodite.

As already mentioned, the two valves of the shell are placed on the sides of the animal. The margin near the hinge (fig. 85, *d*) is dorsal, the opposite (*v*), where the valves open, is ventral; that near the mouth is anterior (*a*), that near the anus and siphons posterior (*p*). In the

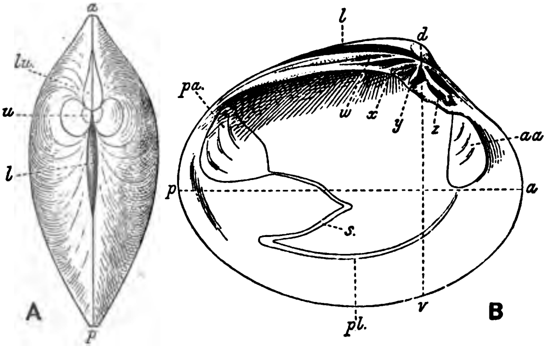

FIG. 85. *Meretrix* (=*Cytherea*) *chione*, Recent. *A*, dorsal view of the two valves. *B*, interior of left valve. × ½.

a, anterior border; *p*, posterior; *d*, dorsal; *v*, ventral; *lu*, lunule; *u*, umbo; *l*, ligament; *aa*, anterior adductor impression; *pa*, posterior adductor; *pl*, pallial line; *s*, pallial sinus; *w*, *x*, *y*, cardinal teeth; *z*, anterior-lateral tooth.

majority of cases the two valves are equal or almost equal in size, and each valve is generally inequilateral. But in some (*e.g. Pectunculus*) the shell is nearly equilateral, in others (*e.g. Ostrea*) it is inequivalve. Each valve may be regarded as a greatly depressed hollow cone, the apices of which form the *umbones* (fig. 85 *A*, *u*); these are sometimes straight (*e.g. Pecten*), but generally curved towards the anterior margin; in a few genera (*e.g. Nucula, Trigonia, Exogyra*) they are directed posteriorly; in *Diceras* they are spiral. There is sometimes in front of the umbones and bounded by a groove an oval depressed area (*lu*), half on each valve; this is termed the *lunule*, and it is important to remember that it is anterior to the umbones. Behind the umbones there is sometimes a somewhat similar, but larger, area, known as the *escutcheon.*

In the interior of the valves various markings may be noticed (fig. 85 *B*), these are produced by the union of the muscles with the shell. The adductors form oval, round, or sometimes elongated depressions (the *adductor impressions, aa, pa*); in the Dimyaria there are two in each valve, one being near the anterior border, the other near the posterior; in the Monomyaria the single adductor impression is usually near the middle of the valve. When, as in the genus *Mya*, etc., the two muscles are placed at equal distances from the hinge-margin, they are of the same size, since they are equally efficient in closing the valves; but in forms like *Mytilus*, where the shell is very inequilateral and the anterior muscle is close to the umbo but the posterior at a considerable distance from it, the latter is much larger than the former, since it is placed in a more advantageous position for closing the valves. For the same reason the single muscle of the Monomyaria is attached near the centre of the valves. Less important than the adductor impressions are those produced by the muscles for the movement of the foot (protractors and retractors); these occur close to the anterior and posterior adductors. Passing from one adductor impression to the other in each valve is a linear depression, the *pallial line* (*pl*); this is caused by the attachment of the muscles of the mantle to the shell. In some forms this line runs evenly between the two adductor impressions and parallel with the margin of the valve; it is then said to be *simple* or *entire*. But in those genera which possess retractile siphons there is a bending in of the pallial line just before reaching the posterior adductor; this indentation is known as the *pallial sinus* (*s*), and is caused by a part of the pallial muscles which serve for the retraction of the siphons.

The hinge is formed by projections known as teeth, which alternate in the two valves, the teeth of one valve fitting into the depressions between those of the other. Several types of hinge may be recognised:—(1) *taxodont*, in which the teeth are numerous and similar in form and size, *e.g.* *Nucula* (fig. 86 *A*): (2) *heterodont*, in which the teeth are few in number and not all of uniform shape and size; some are placed immediately under the umbo and are known as the *cardinal* teeth (fig. 86 *F*), others, termed *laterals*, are placed in front of and behind the umbo, forming the *anterior-* and *posterior-laterals*; some or all of the cardinals or of the laterals may be absent: (3) *schizodont*, in which the teeth are few in number, very thick, and sometimes grooved, *e.g.* *Trigonia* (fig. 86 *B*, *C*): (4) *isodont*, in which there are two strong teeth of equal size in each valve, which fit into corresponding sockets in the other valve, *e.g.* *Spondylus* (fig. 86 *D*, *E*): (5) *desmodont*, in which the teeth are represented by one or more prominent processes developed in connexion with the ligament, *e.g.* *Mya*: (6)

in a few genera (*e.g. Ostrea, Anodonta*) there are no teeth; in some forms this is a primitive character, in others it is the result of degeneration.

The margin of the valve on which the teeth occur is known as the *hinge-line*; generally it is curved, but in some genera like *Arca* it is straight. Sometimes (*e.g. Arca*) there is on each valve, between the hinge-line and the umbo, a flattened triangular part of the shell, known as the *area*; when this is present the umbones of the

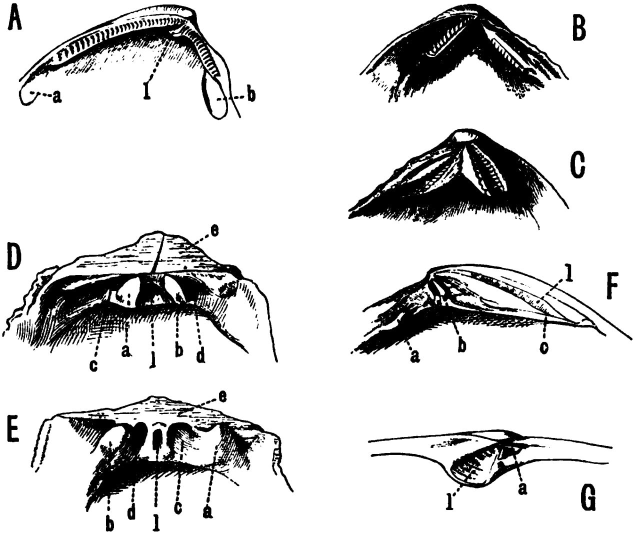

FIG. 86. Some types of hinge. *A*, *Nucula*. *a*, anterior adductor; *b*, posterior adductor; *l*, ligament-pit. *B*, *C*, *Trigonia*. *B*, right valve with two large striated teeth; *C*, left valve with three teeth. *D*, *E*, *Spondylus*; *D*, left valve; *E*, right valve; *a*, *b*, teeth; *c*, *d*, sockets into which the teeth fit; *e*, area; *l*, ligament-pit. *F*, *Lucina* (right valve); *a*, anterior-lateral tooth; *b*, cardinal; *c*, posterior-lateral; *l*, ligament. *G*, *Lutraria* (left valve); *a*, strong Λ-shaped cardinal tooth; *l*, process to which the ligament is attached. All drawn from recent specimens.

two valves are of course widely separated. Some lamellibranchs (*e.g. Pecten*) have, on each side of the umbo, triangular or wing-like extensions of the shell, known as *ears*.

In the brachiopods the valves are opened by divaricator muscles, but in the lamellibranchs the work of these muscles is performed by the ligament. This consists of two parts, the external (fig. 85, *l*), and the internal (sometimes erroneously termed the cartilage). One or other may be absent. The external ligament is composed of horny material; it is usually placed either under the umbones or posterior to them, and is frequently attached to more or less prominent ridges. The internal ligament consists of parallel elastic fibres, and is placed in grooves or sockets along the hinge-line, so that when the valves are closed it is compressed, and, being elastic, tends to force the valves apart—its action is similar to that of a piece of indiarubber placed in the hinge-line of a door. The external ligament acts like a C-spring, and is bent when the valves are closed. Consequently, in order to open the shell, the animal has merely to relax its adductor muscles. Occasionally the ligament is preserved in fossil specimens.

The *length* of a lamellibranch shell is measured from the anterior to the posterior margin (fig. 85 *B*, *a*—*p*), the *breadth* or *height* from the umbo to the ventral margin (*d*—*v*), the *thickness* from one valve to the other at right angles to the lines of length and breadth.

The shell is secreted by the mantle; its structure varies in different groups. Commonly it consists of two calcareous layers; the inner is the *pearly* or *nacreous* layer, and is formed of numerous thin lamellæ; the outer is the *prismatic* layer (fig. 87), and is composed of prisms placed at right angles to the surface of the shell, each prism being encased in a thin membranous sheath, which can be isolated by dissolving the calcareous part of the shell in acid. The external surface is covered by a green or brownish horny layer, the *periostracum* (frequently referred to as the 'epidermis'). The prismatic layer is formed by the margin of the mantle only; the pearly layer by the general surface of the mantle, and this layer gradually encroaches on the former, which consequently cannot afterwards increase in thickness, whereas the pearly layer may do so throughout the life of the animal. The pearly layer is absent in some forms, and the prismatic structure of the outer layer may be indistinct or altogether wanting, and this layer has then a porcellanous appearance. Sometimes the shell consists entirely of aragonite or of calcite; in other cases one layer may be of calcite and the other of aragonite.

The surface of the shell may be smooth, or may be ornamented with radiating or concentric ribs, with striæ, knobs, or spines. Often the exterior shows concentric lamellæ, which represent periods of growth. The part of the shell at the umbo is that which was first formed, and it often differs in ornamentation and form from the other parts. The margins of the valves may be smooth or crenulated; sometimes, as in some species of *Pecten*, the entire shell is corrugated, thus increasing its strength without materially adding to the weight. In many genera the

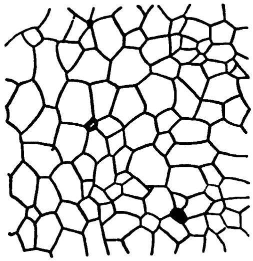

FIG. 87. Section of prismatic layer of recent *Pinna*, parallel to the surface of the shell and at right angles to the prisms. Magnified.

two valves can be completely closed, in others they are always open at some part, and are then said to be *gaping*; this gape occurs most frequently at the posterior end, but sometimes also anteriorly. Sometimes the small embryonic shell, known as the *prodissoconch,* is found at the umbo of the adult shell; this represents the protegulum of the Brachiopods (p. 162) and the protoconch of the Gasteropods and Cephalopods (p. 246).

In order to be able to distinguish the right and left valves we must determine first the anterior and posterior margins. When the soft parts of the animal are present this is easily done; but when the shell only is before the observer the points to be noticed are the following:—

(1) The umbones are generally directed anteriorly.
(2) The lunule is anterior to the umbones.
(3) The external ligament is never entirely anterior to the umbones.
(4) The pallial sinus is posterior.
(5) When one adductor impression only is present, it is the posterior.
(6) When one adductor impression is distinctly larger than the other, the larger is the posterior.

Having found the anterior and posterior margins, the shell should be placed with the dorsal surface uppermost and the anterior margin pointing away from the observer, then the right and left valves will be on his right- and left-hand sides respectively.

Most of the lamellibranchs are free, but a few forms, such as the oyster, are permanently attached by one valve, which is fused to a rock or some other object. In some cases the right valve is fixed, in others the left. The shell in these forms becomes irregular and the fixed valve is larger and thicker than the free valve. Other genera are attached by means of a byssus (p. 189), which often passes out through a notch or sinus in the margin of one or both valves. In the free forms, movement takes place usually by means of the foot, but some genera (*Pecten, Lima*) move by the rapid opening and shutting of the valves. A few are capable of making borings into various substances; thus *Teredo*, the ship-worm, bores into wood, *Lithodomus* and *Saxicava* into limestone, and *Pholas* into various materials, such as sandstone, limestone, gneiss, peat, and amber. Wood perforated by *Teredo* has been found fossil in various formations of Eocene and Oligocene age.

The features which more especially characterise the lamellibranchs as a class are, the absence of a head and of organs of mastication, the bilateral symmetry, the division of the mantle into two lobes, the bivalve shell and the lamellar gills. Although at first sight the shell appears to resemble closely that of the brachiopods, it differs in several important respects, namely, (1) in the valves being right and left, instead of dorsal and ventral, (2) in being generally inequilateral and equivalve, (3) in the occurrence of teeth on both valves, (4) in the presence of a ligament, (5) in the umbones never being perforated for a peduncle, (6) in the microscopic structure of the shell.

Various classifications of the Lamellibranchia have been, from time to time, proposed. By Lamarck this class was divided into the *Monomyaria* and the *Dimyaria*, depending on the presence of *one* or *two* adductor muscles. Between these two groups, however, there are numerous intermediate forms in which the anterior muscle is smaller than the posterior; for these a third division, the *Hetero-*

myaria, was established, but its limits are not well defined, and moreover, in one genus (*Mytilus*) it is found that whilst some species (*e.g. M. edulis*) have both muscles present, in the closely allied *M. latus* the anterior adductor is absent. Another classification, which has been widely adopted, was suggested by S. P. Woodward, and was based on the presence or absence of siphons; the two groups being termed the *Siphonida* and the *Asiphonida*; the former was further divided according as to whether the pallial line was entire (*Integripalliata*) or was provided with a sinus (*Sinupalliata*). Neumayr, Dall, and others have founded groups mainly on the character of the hinge; some of the chief variations in this structure have already been described (p. 193). The classification brought forward by Pelseneer is based on the form and structure of the gills; but since this can only be applied in the case of genera which have living representatives, its details need not be given here. In the present work no division of the Lamellibranchia will be attempted; but the genera will be arranged, as far as possible, according to their affinities.

Nucula[1] (fig. 86 *A*). Shell equivalve, trigonal or oval, closed, posterior side very short; umbones directed posteriorly. Surface smooth or ornamented. Interior nacreous. Margins of valves smooth or crenulated. Hinge-line angular, with a median internal triangular ligament-pit, and numerous sharp teeth. Adductor impressions nearly equal. Pallial line simple. Silurian to present day. Ex. *N. hammeri*, Lias; *N. dixoni*, Bracklesham Beds.

Nuculana (=*Leda*). Similar to *Nucula*. Posteriorly the shell is produced and pointed, and provided with a ridge or carina. Pallial line with a small sinus. Margins smooth. Lunule lanceolate.

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[1] All the genera of mollusca described are marine unless otherwise stated.

Silurian to present day. Ex. *L. lachryma*, Inferior Oolite to Cornbrash ; *L. caudata*, Pliocene to present day.

Ctenodonta. Shell oval or elongated, nearly equilateral, smooth or with concentric striæ. Ligament external. No area. Hinge-line curved or angular, with numerous teeth, which are smaller at the centre. No internal ligament-pit. Pallial line simple. Cambrian to Carboniferous. Ex. *C. pectunculoides*, Ordovician.

Arca. Shell thick, generally equivalve, sub-quadrangular, ventricose, ornamented with radiating ribs and concentric striæ; margins smooth or dentate ; closed or gaping ventrally. Hinge-line straight. Teeth numerous, equal, transverse. Umbones prominent, remote, separated by a lozenge-shaped area, which has numerous ligamental grooves converging from the hinge-margins to the umbones. Adductor impressions sub-equal, the anterior rounded, the posterior divided. Pallial line simple. Ordovician to present day. Ex. *A. tetragona*, Pliocene to present day ; *A. granosa*, Recent.

Cucullæa. Shell similar to *Arca*. Hinge with short central transverse teeth, and two to five lateral teeth nearly parallel to the hinge-margin. Posterior adductor fixed to a thin raised plate. Jurassic to present day. Ex. *C. fibrosa*, Upper Greensand.

Pectunculus (= *Glycimeris*, *Axinæa*). Shell thick, solid, suborbicular, equivalve, almost equilateral. Surface smooth or radially striated. Ligament external. Umbones central, slightly curved posteriorly, separated by a small triangular area provided with diverging grooves for the ligament. Hinge with an arched or semicircular row of numerous, small, strong, transverse teeth, obliterated at the centre in the older forms by the growth of the area. Margins crenulate inside ; adductor impressions sub-equal—the anterior subtriangular, the posterior oval or rounded. Pallial line with a very small sinus. Cretaceous to present day. Ex. *P. glycimeris*, Coralline Crag to present day.

Cardiola. Shell thin, convex, oval, generally inequilateral; umbones prominent, incurved. Surface with well-marked radiating and concentric grooves. Hinge-line straight, probably with very small teeth ; ligamental area large, horizontally grooved. Muscular impressions unknown. The affinities of *Cardiola* have not been satisfactorily determined; some authors consider that it is related to *Cardium*. Silurian and Devonian. Ex. *C. interrupta*, Lower Ludlow, etc.

Trigonia (fig. 86 *B*, *C*). Shell thick, ornamented with rows of tubercles or with radiating or concentric ribs; trigonal, very inequilateral, anterior margin rounded, posterior produced and angular. Generally with a ridge extending from the umbones to the posterior border, cutting off a portion which has a different ornamentation. Umbones anterior, directed posteriorly. Cardinal teeth diverging, striated, two in the right valve, three in the left, the central tooth in the latter being bifid. Ligament marginal, thick. Adductor impressions deep, the anterior smaller than the posterior, and placed near the umbones. A pedal impression in front of the posterior adductor of each valve and also one in the umbo of the left valve. Pallial line simple. Interior nacreous. Lias to present day. Ex. *T. costata*, Inferior Oolite to Corallian; *T. clavellata*, Corallian.

Schizodus. Similar to *Trigonia*; shell thin and smooth, umbones placed anteriorly. Three teeth in each valve. Adductor impressions shallow. Carboniferous and Permian. Ex. *S. obscurus*, Permian.

Anomia. Shell thin, irregular or sub-circular, attached by a calcified byssus, which passes through a rounded sinus near the umbo of the right valve. Right valve flattened, with a central adductor impression; left valve larger, convex, with three impressions of the byssal muscles and one of the adductor. Teeth absent. Lias to present day. Ex. *A. ephippium*, Pliocene to present day.

Modiolopsis. Shell thin, smooth, elongate, very inequilateral, anterior part small, posterior part enlarged. Umbones nearly terminal, close together; a depression crosses the valves obliquely from the umbo. No teeth. Anterior adductor impression deep; posterior adductor large, faintly marked. Ordovician and Silurian. Ex. *M. modiolaris*, Ordovician.

Myoconcha. Similar to *Modiolopsis*, but usually with a long cardinal and a long slender posterior-lateral tooth in the right valve. Carboniferous to Chalk. Ex. *M. crassa*, Inferior Oolite; *M. cretacea*, Chalk.

Mytilus. Shell equivalve, inequilateral, elongated, sub-triangular, posterior border rounded. Umbones sharp, terminal, anterior. Teeth small or absent. Ligament linear, marginal, sub-internal. Anterior adductor impression small, placed near the umbo; posterior large. Trias to present day. Ex. *M. sublævis*, Great Oolite; *M. edulis*, Pliocene to present day.

Modiola. Shell similar to *Mytilus*, but oblong, inflated in front. Umbones obtuse, anterior, but not terminal. Devonian to present day. Ex. *M. modiolus*, Recent; *M. imbricata*, Inferior Oolite to Kellaways Rock.

Lithodomus (= *Lithophagus*). Shell similar to *Modiola*; sub-cylindrical, rounded in front, wedge-like behind. It bores into limestone etc. Carboniferous to present day. Ex. *L. inclusus*, Inferior Oolite to Corallian.

Pinna. Shell generally thin, with coarse prismatic structure (fig. 87), equivalve, inequilateral, wedge-shaped, without ears. Umbones sharp, anterior, terminal. Valves truncate and gaping posteriorly. Hinge-line straight, long. No teeth. Ligament linear, almost entirely internal, lodged in a groove. Posterior adductor large, sub-central; anterior adductor apical. Devonian to present day. Ex. *P. hartmanni*, Lias; *P. affinis*, London Clay.

Conocardium. Shell more or less trigonal, very inequilateral, with radiating ribs; posterior side short, truncated, produced into a long tube; anterior side oblique, compressed, wing-like, gaping. Umbones small, pointed. Hinge-line long, straight, with a posterior-lateral and an indistinct cardinal tooth. Anterior adductor impression large, deep; posterior impression shallow. The truncated end bearing the tube is regarded by some authors as anterior, and the wing-like end as posterior. The affinities of the genus have not yet been determined. Silurian to Carboniferous. Ex. *C. hibernicum*, Carboniferous Limestone.

Gervillia. Shell obliquely elongated, very inequilateral, slightly inequivalve, the left valve a little more convex than the right; umbones almost terminal. Hinge-line straight, broad, with numerous perpendicular, widely-separated ligament-pits; its posterior edge with two or more obliquely-placed obscure teeth. Ears not very distinct from the rest of the shell, the anterior very short, the posterior long. Posterior adductor impression large, sub-central. Trias to Eocene. Ex. *G. anceps*, Lower Greensand.

Inoceramus. Shell variable in form, circular, oval, or oblong; inequilateral, inequivalve, ventricose or compressed, with ears indistinctly limited. Umbones prominent, rather anterior. No teeth. Surface with concentric (or rarely radiating) grooves. Hinge-line straight, long, with numerous parallel, close-set, transverse ligament-pits. Adductor impression rarely visible. Inner layer of shell thin and nacreous, outer layer thick, formed of prismatic fibres. Lias to Chalk. Ex. *I. concentricus*, Gault; *I. brongniarti*, Chalk.

Perna. Shell nearly equivalve, inequilateral, compressed, sub-quadrate or sub-circular, with ears. Umbones anterior. Hinge-line straight, without teeth. Hinge-margin broad, with numerous transverse, elongated ligament-pits placed close together and parallel with one another. Right valve with a byssal sinus. Adductor impression large, sub-central, double. Posterior ear often large, anterior rudimentary. Trias to present day. Ex. *P. mulleti*, Lower Greensand.

Aucella. Shell thin, obliquely elongate, inequilateral, inequivalve, with concentric furrows. Left valve convex, with prominent incurved umbo, and very small anterior ear. Right valve flattened, with obscure ears. Hinge-line straight, short, without teeth. Ligament external. Upper Jurassic and Lower Cretaceous. Ex. *A. keyserlingi*, Speeton Series.

Avicula (= *Pteria*). Shell oblique, inequilateral, inequivalve, left valve more convex than the right. Interior nacreous. Hinge long, straight, with one or two small cardinal teeth and a lamellar lateral tooth. Posterior ear wing-like and longer than the anterior. A byssal sinus under the right anterior ear. Hinge-area small. Ligament partly internal, partly external, in a groove. Posterior adductor impression large, sub-central. Silurian to present day. Ex. *A. media*, Barton Beds etc.

Pseudomonotis. Similar to *Avicula*, but the shell is oval, the left valve large and very convex, and the right valve flattened; the anterior ear small or rudimentary. Devonian to Cretaceous. Ex. *P. echinata*, Cornbrash.

Pterinea. Shell inequivalve; form similar to *Avicula.* Hinge with small transverse anterior teeth, and laminar posterior teeth. Hinge-area large, longitudinally striated. Posterior adductor impression large, shallow; anterior impression small, deep, below the anterior ear. Silurian to Carboniferous. Ex. *P. lævis*, Devonian.

Posidonomya. Shell thin, oblique, oval, equivalve, compressed, with concentric furrows. Umbones small, sub-central. Hinge-line straight, short, without teeth, without ears. Silurian to Jurassic. Ex. *P. becheri*, Carboniferous.

Aviculopecten. Shell somewhat inequilateral; right valve less convex than the left. Hinge-line straight, anterior ear smaller than the posterior; a byssal sinus beneath the anterior ear in the right valve. Ligament in narrow grooves nearly parallel with the hinge-line. Adductor impression large, sub-central. Surface usually radially ribbed. Devonian to Permian. Ex. *A. papyraceus*, Carboniferous.

Ostrea. Shell with lamellar structure, irregular, inequivalve, slightly inequilateral, fixed by the left (larger) valve. Left valve convex, often with radiating ribs or striæ; umbo prominent, sometimes directed anteriorly, sometimes posteriorly. Right valve flat or concave, often smooth. Ligamental cavity triangular or elongated. Hinge without teeth. Adductor impression sub-central; pallial line indistinct. Trias to present day. Ex. *O. deltoidea*, Kimeridgian; *O. edulis*, Pliocene and Recent.

Alectryonia. Similar to *Ostrea.* Both valves with coarse angular folds; edges of valves toothed. Trias to present day. Ex. *A. gregaria*, Corallian; *A. frons*, Lower Chalk.

Gryphæa. Shell similar to *Ostrea*, but free in the adult stage; left valve large and convex, with a prominent incurved umbo. Right valve flattened or concave. Lias to present day. Ex. *G. arcuata* (= *incurva*), Lias.

Exogyra. Similar to *Ostrea.* Shell fixed by the left (larger) valve. Right valve flat, resembling an operculum. Umbones more or less spiral, directed posteriorly. Upper Jurassic to Chalk. Ex. *E. columba*, Upper Greensand.

Pecten. Shell sub-circular, ovate or trigonal, closed, almost equilateral, inequivalve or nearly equivalve. Surface frequently with radiating ribs or striæ, sometimes smooth or with concentric ridges. Hinge-line straight; with well-developed ears, with or without a byssal sinus. Ligament-pit central, and triangular. Adductor impression large, a little excentric. Carboniferous to present day.

Pecten includes a very large number of species, which are grouped into sub-genera and sections, of which some of the more important are :—*Æquipecten* (ex. *Pecten asper*, Upper Greensand, *P. opercularis*, Pliocene and Recent). *Amusium* (ex. *P. pleuronectes*, Recent). *Camptonectes* (ex. *P. lens*, Jurassic). *Chlamys* (see below). *Hinnites* (below). *Neithea* (ex. *P. quadricostatus*, Upper Greensand). *Syncyclonema* (ex. *P. orbicularis*, Chalk).

Chlamys: shell ovoid or trigonal, nearly equivalve, surface with radial ribs. Ears large—the anterior larger than the posterior and with a deep sinus for the byssus on the right valve. Trias to present day. Ex. *P. islandicus*, Pleistocene and Recent.

Hinnites: the young shell is like *Chlamys*; the adult is irregular like *Ostrea*, and is attached by the right valve. Tertiary to present day. Ex. *H. cortesi*, Pliocene.

Pecten (restricted): right valve very convex, left flattened. Ears nearly equal. No byssal sinus. Cretaceous to present day. Ex. *P. maximus*, Pliocene to present day.

Lima. Shell obliquely oval, equivalve, compressed, with radiating striæ or ribs. Valves gaping anteriorly and sometimes posteriorly. Umbones distant, sharp. Hinge-line straight without teeth, with ears; the ears unequal. On each valve a triangular hinge-area, with a central ligament-pit. Adductor impression large, excentric. Two small pedal impressions. Carboniferous to present day. Ex. *L. gigantea*, Lias; *L. cardiiformis*, Middle Jurassic.

Spondylus (fig. 86 *D*, *E*). Shell irregular, with ears, attached by the right valve; surface with radiating ribs which are spiny or foliaceous. Right valve larger (more convex) than the left, with a triangular hinge-area. Two strong teeth in each valve, which fit into corresponding sockets in the other valve; between the teeth a triangular ligament-pit; ligament partly external. Adductor impression large, sub-central. Jurassic to present day. Ex. *S. spinosus*, Chalk; *S. rarispina*, Bracklesham; *S. gæderopus*, Recent.

Plicatula. Similar to *Spondylus*. Surface smooth, folded or scaly. Without ears. Hinge-area obscure. Ligament internal. Adductor impression excentric. Trias to present day. Ex. *P. spinosa*, Lias; *P. inflata*, Chalk.

Chama. Shell irregular, thick, inequivalve, fixed by the umbo of the larger valve (generally the left, sometimes the right). Umbones spiral or sub-spiral, directed anteriorly, that of the fixed valve longer than the other. Surface with concentric lamellæ or spines. The fixed valve larger and much deeper than the other. In each valve a strong cardinal tooth, and sometimes in the inferior valve a narrow curved posterior tooth also. Ligament external, in a deep groove, prolonged towards the umbones. Adductor impressions large, the anterior commencing near the hinge-line. Pallial line simple. Upper Cretaceous to present day. Ex. *C. squamosa*, Barton Beds.

Hippurites (fig. 88). Shell very large and massive, conical or sub-cylindrical, very inequivalve, fixed by the apex of the larger valve. The large (right) valve conical, striated or smooth, and with

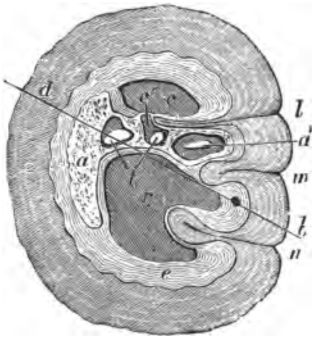

FIG. 88. Transverse section of the large valve of *Hippurites cornuvaccinum*. *r*, umbonal cavity; *e*, internal layer of shell; *d*, external layer; *l*, *m*, *n*, folds; *t*, cardinal teeth; *a*, anterior adductor; *a'*, posterior adductor; *c*, cavity; *c'*, cardinal fossa. Cretaceous. (From Woodward.) Reduced.

three parallel furrows on the cardinal side, and three corresponding folds in the interior; the adductor impression is large and divided. Smaller (left) valve flattened or slightly convex, operculiform, porous, the pores leading into canals; with a central umbo and three prominent teeth, the anterior very large, the two posterior smaller. The smaller valve is formed of two layers, the outer is thin and prismatic, the inner is porcellanous and traversed by numerous canals. The larger valve is also composed of two layers, the outer is formed of small prisms arranged in parallel layers obliquely to the surface of the shell, the inner is porcellanous and formed of thin leaflets. Middle and Upper Cretaceous. Ex. *H. cornu-vaccinum.*

Radiolites. Shell large, thick, valves very unequal. The larger valve conical or cylindrical, generally straight, fixed by its umbo; surface with vertical ribs or horizontal laminæ, and often (on the side opposite to the hinge) with two vertical bands which are smooth or with ornament distinct from that of the rest of the shell; outer layer of shell very thick, formed of polygonal or prismatic cells; inner layer thin, porcellanous, often not preserved; two adductor impressions widely separated. The smaller valve flat or conical, with sub-central or lateral umbo; two straight, elongate teeth; the adductor muscles were attached to plates behind the teeth; shell structure similar to that of the larger valve, but with the external layer thinner. Middle and Upper Cretaceous. Ex. *R. cornu-pastoris.*

Sphærulites. Allied to *Radiolites.* Without vertical bands on the large valve. Middle and Upper Cretaceous. Ex. *S. angeiodes.*

Cardium. Shell convex, nearly equilateral, cordate or oval, generally closed. Umbones prominent, incurved, turned slightly to the anterior side. Surface with radiating ribs, which are often spiny. Margins of valves crenulated. Right valve with one or two cardinal teeth, two anterior-laterals, and one or two posterior-laterals; left valve with two cardinals, one anterior-lateral and one posterior-lateral. Ligament external. Adductor impressions shallow. Pallial line entire. Trias to present day. Ex. *C. aculeatum,* Pleistocene and Recent; *C. edule,* Pliocene to present day.

Protocardia. Similar to *Cardium*, but only the posterior part of the shell is provided with radiating ribs, the remainder with concentric ribs. Jurassic to present day. Ex. *P. hillana*, Upper Greensand.

Cardita. Shell oval or oblong, elongated, very inequilateral, with prominent scaly ribs; often a little gaping and sinuous at its ventral margin. Umbones prominent, anterior. Lunule present. Ligament external. In the right valve two long, parallel cardinal teeth, and a small anterior-lateral tooth. In the left valve one short cardinal (anterior), and one long cardinal (posterior), and a rudimentary posterior-lateral tooth. Adductor impressions large. Pallial line simple. Trias to present day. Ex. *C. calyculata*, Recent.

Venericardia. Shell oval, triangular, or heart-shaped, inequilateral, with radiating ribs. Umbones prominent. Ventral margin crenulated internally, not sinuous. Ligament external. Hinge thick; in the right valve two oblique cardinal teeth and one small anterior-lateral; in the left two diverging cardinal teeth and one elongated posterior-lateral tooth. Adductor impressions unequal. Pallial line simple. Cretaceous to present day. Ex. *V. planicosta*, Bracklesham Beds.

Astarte. Shell thick, inequilateral, more or less trigonal or sub-orbicular, compressed, closed. Surface usually with concentric furrows or striæ. A thick periostracum is present. Umbones prominent. Lunule distinct. Escutcheon elongated. Ligament external. Two cardinal teeth in each valve, lateral teeth rudimentary. Adductor impressions strongly marked; above the anterior one is a pedal impression. Pallial line simple. Trias to present day. Ex. *A. omalii*, Coralline Crag.

Opis. Shell trigonal, cordiform, convex, with an oblique keel extending from the umbo to the posterior border. Umbones prominent, incurved or sub-spiral. Lunule large and very deep. Surface generally with concentric furrows. One cardinal tooth in the right valve, two in the left. Pallial line simple. Trias to Chalk. Ex. *O. lunulatus*, Inferior Oolite.

Crassatellites (=*Crassatella*). Shell solid, oblong or subtrigonal, attenuated behind. Surface smooth or concentrically furrowed. Margins of valves smooth or crenulated. Umbones small, close together. Lunule distinct. Ligament internal, placed in a pit under the umbo. Hinge with two (sometimes three) cardinal teeth, and some small laterals. Adductor impressions deep. Pallial line simple. Cretaceous to present day. Ex. *C. sulcata*, Barton Beds.

Hippopodium. Shell very thick, oblong; surface with lines of growth. Umbones large, anterior. Hinge thick, with one oblique tooth which may disappear in old specimens. Adductor impressions deep. Pallial line simple. Lias to Great Oolite. Ex. *H. ponderosum*, Lower and Middle Lias.

Cardinia. Shell trigonal, oval, or oblong, very inequilateral, compressed, thick, marked by lines of growth. Interior not nacreous. Umbones small, sharp, close together. Ligament external. Cardinal teeth small or obsolete; in the right valve one anterior-lateral tooth, in the left, one posterior-lateral. Impression of anterior adductor very deep. Pallial line simple. Trias to Middle Jurassic (chiefly Lias). Ex. *C. listeri*, Lias.

Unio. Shell oval or elongated, with a thin periostracum. Surface smooth, striated or folded; interior nacreous. Umbones more or less anterior, often corroded. Ligament external, elongated. In the right valve there are two anterior-lateral teeth and a long lamellar posterior-lateral tooth; in the left valve one anterior-lateral, one cardinal, and two long lamellar posterior-lateral teeth. Adductor impressions very deep, especially the anterior. Pallial line simple. Inferior Oolite to present day. Lives in fresh water. Ex. *U. littoralis*, Pleistocene and Recent.

Anodonta. Allied to *Unio.* Miocene (perhaps Purbeckian) to present day.

Carbonicola (=*Anthracosia*). Similar to *Unio*, but the anterior part of shell is broad and tumid, the posterior part narrow and compressed; usually a constriction at the ventral border. Hinge-plate triangular, with or without cardinal teeth, no laterals. Anterior adductor large, near the margin. Pedal impression above the anterior adductor. Carboniferous and Permian. Probably freshwater. Ex. *C. robusta*, Coal Measures.

Anthracomya. Differs from the preceding chiefly in having the posterior part of the shell broad and expanded. Hinge-plate small, with a cardinal and one posterior-lateral tooth. Carboniferous. Probably freshwater. Ex. *A. adamsi.*

Cyprina. Shell orbicular or oval, convex, with concentric striæ and a thick periostracum. Umbones prominent, incurved. Ligament external, prominent. No lunule. In each valve two cardinal teeth; in the right valve two anterior- and one posterior-lateral; in the left valve one anterior- and one indistinct posterior-lateral. Adductor impressions oval. Pallial line entire. Margins of valves smooth. Lias to present day. Ex. *C. islandica*, Coralline Crag to present day.

Isocardia. Similar to *Cyprina*. Umbones inflated, curved anteriorly or spirally inrolled. In each valve two nearly parallel cardinal teeth and one posterior-lateral. Jurassic to present day. Ex. *I. cor*, Coralline Crag to present day.

Lucina (fig. 86 *F*). Shell orbicular or oval, slightly inequilateral, usually ornamented with concentric lines or ridges. Lunule distinct. An oblique furrow extends from the umbo to the posterior border. Hinge usually with two cardinal teeth and one or two lateral in each valve; the lateral, or the cardinal, may be absent. Ligament elongated, external, sometimes partly internal. Adductor impressions well marked, the anterior elongated and placed mainly within the pallial line, the posterior oval. Pallial line entire. Margins of valves smooth or finely crenulated. Trias to present day. Ex. *L. borealis*, Coralline Crag to present day.

Cyrena. Shell cordiform, oval, or trigonal, usually with concentric ridges; umbones often corroded. Hinge with three cardinal teeth; one anterior- and one posterior-lateral in the left valve, and two of each in the right valve. Ligament prominent, external. Pallial line usually entire. Lias to present day. Lives in fresh and brackish water. Ex. *C. ceylanica*, Recent.

Corbicula. Similar to *Cyrena*, but with the lateral teeth lamellar and finely striated. Eocene to present day. Freshwater. Ex. *C. fluminalis*, Pliocene to present day.

Venus. Shell thick, oval, inflated; surface smooth, or with ribs or concentric lamellæ; lunule distinct. Margins of valves finely crenulate. Hinge-plate wide; in each valve three cardinal teeth, often bifid, no lateral teeth. Ligament external, prominent. Pallial sinus small. Middle Jurassic to present day. Ex. *V. casina*, Pliocene to present day.

Meretrix (=*Cytherea*) (fig. 85). Shell thick, ovate, sub-trigonal, smooth or with concentric striæ. Margins of valves not crenulate. Lunule well marked. Ligament external. Hinge thick, with three cardinal teeth in each valve, two anterior-lateral in the right, and one in the left valve. Pallial sinus angular. Jurassic to present day. Ex. *M. incrassata*, Headon Beds.

Dosinia (=*Artemis*). Shell orbicular, compressed, with concentric ridges or striæ. Lunule depressed. Escutcheon narrow. Ligament sunk. Three cardinal teeth in each valve, one anterior-lateral in the left valve, and two (rudimentary) in the right. Margins smooth. Pallial sinus very deep. Upper Cretaceous to present day. Ex. *D. exoleta*, Coralline Crag to present day.

Tellina. Shell oval, transversely-elongate, or sub-orbicular, slightly inequivalve, compressed, rounded in front, attenuated behind, and furnished with an oblique fold from the umbo to the posterior border. Margins of valves smooth. Two cardinal teeth in each valve, and one anterior- and one posterior-lateral, which are often indistinct in the left valve. Ligament external, prominent. Pallial sinus very deep. Jurassic to present day. Ex. *T. balthica*, Pliocene to present day.

Psammobia. Shell elongate, sub-equilateral, gaping at the ends, anterior side rounded, posterior side more or less truncate and angular. Surface smooth or with striæ. Ligament external, thick, joined to prominent ridges. Usually two cardinal teeth in each valve, some being bifid. Adductor impressions near the dorsal border. Pallial sinus very deep. Eocene (perhaps Cretaceous) to present day. Ex. *P. rudis*, Oligocene; *P. ferroensis*, Coralline Crag to present day.

Mactra. Shell oval or trigonal, nearly equilateral, smooth or with concentric striæ. Internal ligament in a large triangular pit. External ligament in a groove. In front of the internal ligament-pit is a bifid cardinal tooth (in the form of an inverted V); anterior- and posterior-lateral teeth well-marked, compressed, double in the right valve, single in the left. Adductor impressions semicircular. Pallial sinus round or angular. Cretaceous to present day. Ex. *M. ovalis*, Red Crag to present day.

Solen. Shell very long, sub-cylindrical, straight, smooth or finely striated, the dorsal and ventral margins parallel; gaping at both extremities. Margins of valves smooth. Umbones at the anterior end. Hinge terminal, with one cardinal tooth in each valve. Ligament long, external. Anterior adductor impression elongated, parallel to the dorsal margin. Pallial sinus short. Eocene (perhaps earlier) to present day. Ex. *S. obliquus*, Bracklesham Beds; *S. vagina*, Recent.

Mya (fig. 84). Shell oblong, gaping at both ends, particularly at the posterior; the left valve a little smaller than the right. In the right valve one small cardinal tooth; in the left valve a large spoon-like process to which the internal ligament is fixed. Anterior adductor impression elongated. Pallial sinus large and rounded. Eocene to present day. Ex. *M. truncata*, Coralline Crag to present day.

Corbula. Shell oval, inequivalve, closed, rounded in front, somewhat angular and contracted behind, with a ridge passing from the umbo to the posterior angle. Surface generally with concentric grooves. Umbones prominent. Right valve larger and more convex than the left, and with a strong cardinal tooth in front of the ligament-pit, and also a posterior cardinal tooth; left valve with a spoon-like process for the internal ligament, and one posterior cardinal tooth. Adductor impressions well marked. Pallial line slightly sinuous posteriorly. Trias to present day. Ex. *C. ficus*, Barton Beds.

Panopea. Shell equivalve, inequilateral, oblong, thick, concentrically striated, gaping at each end, especially at the posterior. Ligament external, on a prominent ridge. One cardinal tooth in each valve. Pallial sinus very deep. Cretaceous to present day. Ex. *P. faujasi*, Coralline Crag to present day.

Saxicava. Shell small, more or less oblong, gaping; umbones anterior. Ligament external. Teeth absent in the adult, one or two cardinals present in the young. Pallial line not continuous, sinuous. *Saxicava* bores into rocks etc. Jurassic to present day. Ex. *S. rugosa*, Coralline Crag to present day.

Ceromya. Shell heart-shaped, inflated, inequilateral, finely granular, with concentric grooves. Left valve not quite so convex as the right. Anterior side short, posterior longer and compressed. Umbones prominent, anterior, curved forward. Hinge thickened, with a ridge behind the umbones; teeth absent. Pallial line sinuous. Jurassic. Ex. *C. concentrica*, Inferior Oolite to Cornbrash.

Grammysia. Shell elongate-ovate, very inequilateral, ornamented with concentric furrows, and one or more radial folds passing from the umbo to the postero-ventral border. Umbones placed anteriorly. Lunule very deep. Hinge-margin thick, without teeth. Anterior adductor very small, posterior large. Pallial line simple. The systematic position of *Grammysia* is uncertain. Silurian and Devonian. Ex. *G. cingulata*, Silurian; *G. hamiltonensis*, Devonian.

Pleuromya. Shell transversely elongated, anterior side short, posterior long and generally compressed, sometimes gaping; surface with concentric folds. Hinge without teeth, but with a thin projecting plate at the margin. Adductor impressions faintly marked; pallial sinus deep. Trias to Cretaceous. Ex. *P. donacina*, Corallian and Kimeridgian.

Gresslya. Shell oval, elongate, very inequilateral, smooth or with concentric furrows; anterior side high and inflated, posterior side narrowing and somewhat compressed. Umbones anterior, close together; lunule sometimes well marked. Right valve a little higher and larger than the left. Adductor impressions shallow; pallial sinus deep. Behind the umbo of the right valve is a tooth-like projection and an internal plate—the latter appears as a furrow in casts of the shell. Jurassic. Ex. *G. gregaria*, *G. abducta*, Inferior Oolite.

Pholadomya. Shell thin, translucent, oblong or oval, ventricose, equivalve, gaping posteriorly and sometimes anteriorly. Anterior side short and rounded. Surface with radiating ribs crossed by concentric striæ. Umbones prominent. Ligament external. Hinge without teeth or with a small transverse tubercle. Adductor impressions very faint. Pallial sinus deep. Lias to present day. Ex. *P. margaritacea*, London Clay.

Homomya. Similar to *Pholadomya.* Without radial ribs; surface smooth or ornamented with fine granules. Trias to Cretaceous. Ex. *H. gibbosa*, Inferior and Great Oolites.

Goniomya. Similar to the last two, but with V-shaped ribs pointing ventrally. Lias to Cretaceous. Ex. *G. literata*, Inferior Oolite to Corallian.

Thracia. Shell thin, oblong, compressed, attenuated and gaping posteriorly; surface smooth or concentrically striated. Umbones turned a little to the posterior side. Right valve larger than the left. Hinge with a stout calcareous process or ossicle in each valve. External ligament short and prominent. Adductor impressions small. Pallial sinus not very deep. Trias to present day. Ex. *T. pubescens*, Coralline Crag to present day.

Pholas. Shell elongate, cylindrical, gaping at both ends. Surface with spiny ridges, best marked in front. On the dorsal region are one or more calcareous plates. No teeth; no ligament. In the interior, under the umbones, is a process for the insertion of the muscle of the foot. Pallial sinus very deep. *Pholas* bores into rocks etc. Lias to present day. Ex. *P. cylindrica*, Red Crag; *P. dactylus*, Recent.

Teredo. Shell more or less globular, gaping at the ends, valves tri-lobed, with concentric striæ. In the interior, under the umbones, is a long narrow plate for the insertion of the pedal muscle. Posterior part covered by a long, calcareous tube, which is subcylindrical, straight or curved, and often with partitions. *Teredo* perforates wood. Jurassic to present day. Ex. *T. norvegica*, Coralline Crag to present day.

Distribution of the Lamellibranchia.

All the Lamellibranchs are aquatic animals, and by far the larger number are marine. The marine forms range from the shore-line down to a depth of 2900 fathoms; they are most abundant in shallow water, and are scarce at depths greater than 500 fathoms, but the following, and a few other genera, have been found below 1500 fathoms:—*Nucula, Nuculana, Arca, Limopsis, Malletia, Verticordia, Cuspidaria* (= *Neæra*).

Two genera of Lamellibranchs have been recorded from the Lower Cambrian of North America; in England the earliest forms appear in the Tremadoc Beds. They are rather rare in the Ordovician, but become fairly numerous in the Silurian, and afterwards gradually increase in importance, reaching their maximum at the present day. Many of the genera have a rather extended range in time.

Fresh or brackish water Lamellibranchs are generally rare in the Palæozoic and Mesozoic formations. Probably the earliest form is *Archanodon jukesi* (from the Old Red Sandstone) which resembles the living freshwater mussel *Anodonta*. In the Coal Measures several species of *Carbonicola, Anthracomya,* and *Naiadites* occur. The living type *Unio* has been found in the Inferior Oolite of Yorkshire, and is fairly common in the Purbeckian and Wealden of the south of England, where it is associated with *Corbicula*. Freshwater lamellibranchs also occur in the Woolwich Beds, the Oligocene deposits, and in the Pleistocene river-gravels.

The principal genera of Lamellibranchs found in the different systems are as follows:

Cambrian. *Ctenodonta, Glyptarca.*

Ordovician. *Ctenodonta, Cyrtodonta* (= *Palæarca*), *Glyptarca, Modiolopsis.*

Silurian. *Ctenodonta, Cardiola, Avicula, Pterinea, Ambonychia, Modiolopsis, Grammysia.*

Devonian. *Ctenodonta, Cardiola, Pterinea, Aviculopecten, Actinopteria, Megalodon, Conocardium.*

Carboniferous. *Aviculopecten, Posidonomya, Pinna, Conocardium, Carbonicola* (= *Anthracosia*), *Anthracomya, Edmondia, Sanguinolites.*

Permian. *Bakevellia*, *Schizodus.*

Trias. *Nucula*, *Nuculana*, *Palæoneilo*, *Arca*, *Myophoria*, *Gervillia*, *Hoernesia*, *Monotis*, *Halobia*, *Ostrea*, *Pecten* (subgenera), *Lima*, *Avicula*, *Cassianella*, *Cardium*, *Cardita*, *Megalodon.*

Jurassic. *Nucula*, *Nuculana*, *Arca*, *Macrodon*, *Trigonia*, *Myoconcha*, *Modiola*, *Hippopodium*, *Avicula*, *Pseudomonotis*, *Gervillia*, *Perna*, *Ceromya*, *Pinna*, *Ostrea*, *Gryphæa*, *Alectryonia*, *Pecten* (various subgenera of), *Lima*, *Diceras*, *Cardium*, *Unicardium*, *Astarte*, *Opis*, *Pachyrisma*, *Cardinia*, *Pleuromya*, *Gresslya*, *Pholadomya*, *Homomya*, *Thracia.*

Cretaceous. *Nucula*, *Arca*, *Cucullæa*, *Trigonia*, *Modiola*, *Myoconcha*, *Gervillia*, *Inoceramus*, *Perna*, *Aucella*, *Ostrea*, *Exogyra*, *Alectryonia*, *Pecten* (the subgenera *Chlamys*, *Syncyclonema*, *Neithea* etc.), *Lima*, *Spondylus*, *Plicatula*, *Hippurites*, *Radiolites*, *Sphærulites*, *Cardium*, *Protocardia*, *Unio*, *Cyprina*, *Pholadomya.*

Eocene. *Nucula*, *Arca*, *Pectunculus*, *Pecten* (*Chlamys* etc.), *Chama*, *Cardium*, *Venericardia*, *Cardita*, *Astarte*, *Crassatellites*, *Cyprina*, *Lucina*, *Meretrix* (= *Cytherea*), *Psammobia*, *Tellina*, *Corbula*, *Panopæa*, *Pholadomya.*

Oligocene. *Mytilus*, *Dreissensia*, *Ostrea*, *Cyrena*, *Corbula*, *Erodona* (= *Potamomya*), *Lucina*, *Meretrix* (= *Cytherea*), *Psammobia.*

Pliocene. *Nucula*, *Pectunculus*, *Mytilus*, *Pecten*, *Chlamys*, *Cardium*, *Cardita*, *Astarte*, *Cyprina*, *Isocardia*, *Lucina*, *Venus*, *Dosinia* (= *Artemis*), *Tellina*, *Mya.*

CLASS II. GASTEROPODA.

The Gasteropoda include even a larger number of forms than the preceding class; well-known examples are the snail, the whelk, and the cowry. The bilateral symmetry, so characteristic of the lamellibranchs, is generally to a large extent obliterated, owing to the twisting of the visceral mass and the atrophy of some of the organs on one side of the body. There is a distinct head, which bears one or two pairs of tentacles, and usually also eyes. On the ventral surface of the body is the foot; this is usually large and sole-like and used for crawling, but in the Heteropods it is in the form of a flattened fin, and in the Pteropods it is wing-like. The mantle is never divided into two lobes. Respiration takes place in some cases through the skin, but generally by means of a lung-cavity or by gills; the latter are placed in a sac formed by the mantle; sometimes they are present on both sides of the body, but very often the original left gill has disappeared. In some forms the mantle, at the opening of the gill-sac, is produced into a tube, known as the *siphon*, by means of which water passes to the gills. The heart is on the dorsal surface, and consists of a ventricle and usually one, but in some cases two auricles. In many forms the gills are placed in front of the heart, but in others behind it. The mouth is at the anterior end of the body; the anus is occasionally posterior, but as a rule it is placed near the opening of the gill chamber. On the floor of the cavity of the mouth is a dental apparatus, known as the *odontophore*: this consists of a chitinous ribbon (the *radula* or *lingual ribbon*) placed on a cartilaginous ridge; the radula bears numerous teeth which are placed in rows, and it serves as a rasping organ. The arrangement of the teeth varies in different genera and is of considerable importance in classification, but since the radula has never been definitely recognised in fossil forms, it can only be used by the palæontologist in the case of genera which have existing representatives. The nervous system consists of ganglia which are connected by nerve-cords. Typically there are three pairs of principal ganglia—the *cerebral* placed above the œsophagus, and the *pleural* and *pedal* placed below it; a visceral nerve-cord, which may bear ganglia, comes off from the pleural ganglia, and forms a loop ventral to the intestine. In some gasteropods (the Euthyneura) this loop is simple, but in others (the Streptoneura) one side is bent over so that the loop forms a figure of 8. Some gasteropods are unisexual, others hermaphrodite.

In the majority of the gasteropods a shell is secreted by the mantle; in a few forms, as for instance the slugs, it is internal, but usually it is external and covers the visceral mass. The shell, except in *Chiton* and its allies, consists of a single piece, and is hence said to be *univalve.* In the limpet (*Patella*) it has the form of a hollow cone; but in most cases it consists of a long tube, open at one end, and tapering to a point at the other. This tube is generally coiled into a screw-like spiral, each coil being termed a *whorl*; in a few genera (*e.g. Vermetus, Siliquaria*) the whorls are separated, but as a rule they are in contact (fig. 89), the line between two contiguous whorls being known as the *suture* (*su*). All the whorls, except the last one, together form the *spire* (*S*) of the shell, the point of which is termed the *apex* (*a*). The last whorl is nearly always larger than the preceding, frequently very much so, and the part of it farthest from the apex forms the *base* of the shell. The spire varies in form in different genera and species; sometimes it is composed of a large number of whorls, sometimes of few, and it may be long, short, or depressed. The angle of the spire (*spiral angle*) will consequently also vary; this is measured by lines drawn from the apex to the base of the shell on opposite sides of the exterior of the whorls. The coiling of the shell is usually *dextral*; so that when the apex of the shell is pointed away from the observer (as in fig. 89) the aperture will be on the right-hand side; in a few cases it is *sinistral,* when the aperture will be on the left.

Frequently the inner parts of the whorls coalesce, and form an axial pillar extending from the apex to the base of the shell (fig. 89) and known as the *columella.* In other cases the inner parts do not fuse, and in the place of the columella there is left a tube-like space, extending from the base of the shell a greater or less distance towards the apex; this space, which opens at the base of the shell, is called the *umbilicus.* When there is a columella the shell is often said to be *imperforate,* when instead there is an umbilicus it is *perforate.* The opening of the umbilicus sometimes becomes partly filled up with a shelly growth,

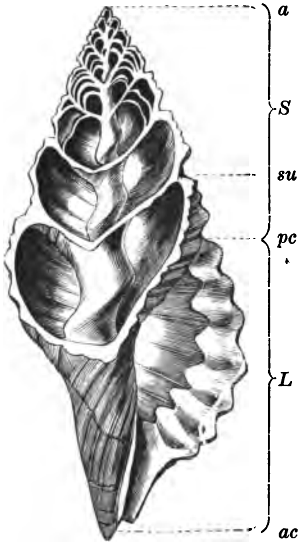

Fig. 89. Longitudinal section of *Lotorium* (=*Triton*) *corrugatum.* The upper part of the spire has been partitioned off many times successively. *a*, apex; *su*, suture; *S*, spire; *L*, outer lip of the aperture; *ac*, anterior canal; *pc*, posterior canal. (From Woodward.)

known as *callus.* The animal is attached to the columella by means of a muscle, the contraction of which enables it to withdraw completely into the shell; but, when not retracted, the coiled visceral mass only is covered by the shell.

Usually the cavity of the gasteropod shell is continuous from the apex to the aperture, but in a few cases partitions are thrown across the earlier parts of the shell (fig. 89), forming chambers which remain empty. The form of the aperture varies considerably in different genera and is of great importance in classification; in shape, it may be circular, oval, elongate, oblong, etc. Its margin is termed the *peristome*: the outer part forms the *outer lip* (*L*), the inner part (that next the columella) the *inner lip*. As the gasteropod crawls along, the shell is carried on the dorsal surface of its body with the apex directed backward and upward, and the aperture downward; consequently the part of the aperture farthest from the apex is *anterior*, the opposite (nearest the apex) is *posterior*. Sometimes, as in *Natica,* there is no break in the peristome, and it is then said to be entire or *holostomatous*; in other cases the anterior border is notched or produced into a tube (*ac*) in which the siphon is placed, and these forms are said to be *siphonostomatous*; sometimes there is also at the posterior border another canal (*pc*), in which the excurrent or anal siphon is placed. The outer lip may be thin and sharp, or thickened. Sometimes it is curved outwards, and is then said to be *reflected*; or it is curved inwards—*inflected.* Its margin may be even, or crenulated, or produced into processes.

Many genera have a calcareous or horny plate, known as the *operculum,* attached to the posterior part of the foot; this is so arranged that when the animal withdraws into its shell the operculum more or less completely closes the aperture. It has been considered by some as a second valve, but more probably represents the byssus of the lamellibranch. The operculum is seldom preserved fossil; its form varies considerably in different genera, in some (*Turbo*) it is of very large size with the inner surface flattened and the outer convex; it may have a spiral structure, and is then sometimes formed of a large number of whorls (*multispiral*) as in *Trochus*, or of a few whorls (*paucispiral*) as in *Littorina*. When not spiral it may be *concentric*, if growth takes place equally all round; it is then marked with concentric lines, the nucleus being nearly central, as in *Viviparus*; or it may be *unguiculate* or *claw-shaped* when the nucleus is at the apex as in *Fusus*.

The form of the shell in the spiral gasteropods varies considerably, depending on the arrangement of the whorls in one plane or in a helicoid spiral, on the spiral angle, on the number and shape of the whorls, on the size of the last whorl and whether it conceals the earlier whorls or not. The chief types are the following:—

1. *Discoidal;* the whorls all in one plane, as in *Planorbis*.
2. *Conical* or *trochiform;* conical with a flat base, as in *Trochus*.
3. *Turbinate;* conical with a convex base, as in *Turbo*.
4. *Turreted* or *elongated;* as in *Turritella*.
5. *Fusiform;* tapering to each end, as in *Fusus*.
6. *Cylindrical;* as in *Pupa*.
7. *Globular;* as in *Natica*.

8. *Convolute;* when the last whorl covers all the others and the aperture is consequently as long as the shell, as in *Cypræa.*

9. *Auriform;* aperture very large and spire very short, as in *Haliotis.*

The surface of the shell is frequently ornamented with spines, knobs, ribs, or striæ; these are said to be *longitudinal* or *spiral* when they run parallel with the sutures, and *transverse* when they run across the whorls from suture to suture. When rows of spines, or lamellar processes, extend across all the whorls from the apex to the base of the shell, as in *Murex,* we have what are termed *varices.* The surface of the shell in recent gasteropods is generally coloured, often variegated; in fossil examples the colour has nearly always disappeared, but a few specimens, from various formations, even as early as the Carboniferous, have been found showing the colour more or less perfectly preserved. The shell consists of an outer chitinous layer, and of a calcareous layer which is thick and porcellanous; in some cases there is also an inner nacreous or pearly layer.

The Gasteropoda are divided into two sub-classes:—(1) Isopleura, (2) Anisopleura.

SUB-CLASS I. ISOPLEURA.

The Isopleura, or Polyplacophora, include *Chiton* and its allies. The body is bilaterally symmetrical and more or less elongated, with the anus at the posterior end. There are numerous (6 to 80) pairs of gills, which are placed in a groove between the foot and the mantle. A nerve-ring surrounds the œsophagus, and from it two nerves come off on each side and extend to the posterior end of the body; ganglia are poorly or not at all developed. The shell consists of eight plates placed in a longitudinal row on the dorsal surface of the body; each plate usually overlaps the one behind it, and a flexible band or girdle encircles the whole series of plates.

All the forms in this group are marine; they live chiefly in quite shallow water, but a few examples have been found at great depths. Although of great antiquity and represented by a large number of living species, the Isopleura are rarely found fossil. The earliest form (*Priscochiton*) occurs in the Ordovician; *Helminthochiton* is found in the Silurian; *Gryphochiton* in the Carboniferous; *Lepidopleurus*, *Chiton*, and others in the Tertiary.

SUB-CLASS II. ANISOPLEURA.

The body is asymmetrical, owing to the twisting of the visceral mass. There are not more than two gills. The shell consists of one piece and is usually spiral. There are two orders, (1) Streptoneura, (2) Euthyneura.

ORDER I. STREPTONEURA.

In the Streptoneura (or Prosobranchia) the visceral nerve-còrd is twisted into a figure of 8. Usually one gill only is present, and it is placed in front of the heart. An operculum is found in most cases.

Patella. Shell conical, oval or sub-circular; apex sub-central or excentric, nearer the anterior border, often curved forwards; surface with radiating ribs or striæ, rarely smooth. Margin simple or spinose. Muscular impression horse-shoe shaped, open in front. Jurassic (perhaps Palæozoic also) to present day. Ex. *P. vulgata*, Pliocene to present day.

Pleurotomaria. Shell trochiform, conical, turbinate, or discoidal; interior nacreous. Umbilicus present or absent. Aperture sub-quadrate or oval, outer lip sharp, with a slit which, as the shell grows, becomes filled up, leaving a band on the whorls, toward which the lines of growth are directed obliquely backwards. Operculum horny. Upper Cambrian to present day. Ex. *P. anglica*, Lias; *P. ornata*, Inferior Oolite.

Murchisonia. Shell turreted, with many, more or less angular whorls, provided with a band as in *Pleurotomaria.* Aperture oblong, with a slit, and a very short anterior canal. Ordovician to Trias. Ex. *M. verneuiliana*, Carboniferous Limestone.

Bellerophon (fig. 90). Shell globular, usually with an umbilicus on each side; whorls few, embracing, symmetrically coiled in one plane. Aperture sub-circular or oval, with a deep median slit, which is replaced by a band or keel dividing the shell into two similar parts; columellar edge often with callus. Cambrian to Permian. Ex. *B. tenuifascia*, Carboniferous Limestone.

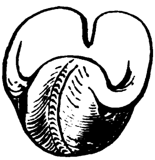

FIG. 90. *Bellerophon*, from the Carboniferous Limestone, showing the slit in the aperture. × ⅔.

Fissurella. Shell similar to *Emarginula*, but more or less depressed; apex perforated and nearer the anterior than the posterior border; no marginal slit. Muscular impression as in *Patella.* Jurassic (perhaps Carboniferous) to present day. Ex. *F. crassa*, Recent; *F. græca*, Coralline Crag to present day. *Fissurella* is divided into several sub-genera; many of the fossil species belong to the subgenus *Fissuridea.*

Emarginula. Shell conical, surface ornamented with a trellis-work of longitudinal and transverse ribs, apex curved posteriorly. Anterior border with a well-marked slit, which becomes filled up during growth, leaving a raised band. Muscular impression horse-shoe shaped. Jurassic (perhaps Carboniferous) to present day. Ex. *E. fissura*, Coralline Crag to present day.

Euomphalus. Shell depressed, discoidal or conical, with a wide and large umbilicus; whorls convex with a ridge on the upper surface. Aperture polygonal; outer lip with a slit on its upper surface. Silurian to Trias. Ex. *E. pentangulatus*, Carboniferous Limestone.

Omphalotrochus (=*Horiostoma* of some authors). Form similar to *Euomphalus*. Whorls ornamented with longitudinal keels and numerous transverse striæ or fine ribs. Aperture without a slit. Ordovician to Carboniferous. Ex. *O. discus*, Silurian.

Turbo. Shell solid, turbinate or conical, whorls convex, interior nacreous. Aperture large, circular, entire, slightly produced anteriorly; outer lip sharp. Columella curved, flattened. Imperforate or with a small umbilicus. Operculum thick, calcareous, exterior convex, interior flat and spiral, nucleus central or subcentral. Jurassic (perhaps also Palæozoic) to present day. Ex. *T. marmoratus*, Recent; *T. rugosus*, Pliocene to present day. There are numerous sub-genera.

Phasianella. Shell elongated, oval or oblong, smooth, polished, without an umbilicus, interior not nacreous. Aperture oval, entire, rounded anteriorly, angular posteriorly; outer lip thin, simple, sharp. Columella smooth, flattened. Operculum calcareous, with an excentric nucleus. Upper Cretaceous (or earlier) to present day. Ex. *P. australis*, Recent; *P. gosauica*, Upper Cretaceous.

Amberleya. Shell turbinate, elongate, without umbilicus. Whorls ornamented with several longitudinal keels which are usually spiny or nodular; between the keels are numerous transverse striæ or fine ribs. Base rounded. Aperture sub-oval; outer lip often crenulated. Trias to Cretaceous (chiefly Jurassic). Ex. *A. ornata*, Inferior Oolite.

Cirrus. Shell sinistral, conical or turbinate, or sometimes nearly discoidal, with a very large umbilicus. Spire acute. Whorls irregular, ornamented with strong transverse nodular ribs and finer longitudinal ribs; last whorl large. Aperture rounded, entire. Trias to Inferior Oolite. Ex. *C. nodosus*, Inferior Oolite.

Trochus. Shell conical, whorls numerous and flat or slightly convex, spire sharp, interior nacreous; base flat or nearly so, angular at the periphery. Aperture entire, rhomboidal; outer lip sharp, oblique. Columella twisted, with a prominent anterior tooth-like protuberance or a fold. Operculum horny, multispiral, nucleus central. Trias to present day. Ex. *T. niloticus*, Recent. There are numerous sub-genera.

Nerita. Shell thick, solid, ovoid or semi-globose, without an umbilicus; interior not nacreous. Spire very short. Surface smooth or with spiral ribs. Aperture semicircular, entire; outer lip thick, the interior generally denticulate; inner lip flattened, with callus, and a straight denticulate border. Operculum calcareous, nucleus excentric. Cretaceous to present day. Ex. *N. ustulata*, Recent; *N. globosa*, London Clay and Bracklesham Beds.

Neritina. Form similar to *Nerita*. Shell relatively thin, usually smooth. Outer lip sharp, not thickened, with interior not denticulate. Eocene (perhaps earlier) to present day. Ex. *N. aperta*, Headon Beds; *N. zebra*, Recent.

Macrochilina (=*Macrocheilus*). Shell elongate-oval, with sharp spire, and last whorl high. Surface smooth or with growth-line. No umbilicus. Aperture ovate, angular behind, sometimes with a shallow anterior canal; outer lip thin, inner lip with a weak anterior fold. Silurian to Trias. Ex. *M. arculatus*, Devonian.

Loxonema. Shell turreted, spire very long; whorls convex, ornamented with sinuous growth-line. No umbilicus. Aperture long, enlarging in front, with shallow canal; outer lip sharp, sinuous. Silurian to Trias (chiefly Carboniferous). Ex. *L. constrictum*, Carboniferous.

Pseudomelania. Shell elongate, with many nearly flat whorls, without umbilicus, spire long, surface smooth or with growth-lines. Aperture oval, entire, rounded in front, narrowed and angular behind; outer lip sharp. Columella smooth. Trias to Eocene. Ex. *P. heddingtonensis*, Corallian.

Scala (=*Scalaria*). Shell turreted, spire elongate; whorls numerous, very convex, sometimes separated, ornamented with strong transverse ribs or sometimes with lamellæ, frequently with spiral ribs also. Umbilicus more or less distinct. Aperture circular, entire, margin thickened. Operculum horny, paucispiral. Trias to present day. Ex. *S. scalaris*, Recent; *S. grœnlandica*, Red Crag to present day.

Solarium. Shell conical, depressed, angular at the periphery. Aperture entire, sub-quadrate; lip sharp. Umbilicus wide and deep, limited by a sharp edge which is generally crenulated. Operculum horny, spiral. Jurassic to present day. Ex. *S. perspectivum*, Recent; *S. canaliculatum*, Barton and Bracklesham Beds.

Purpuroidea. Shell thick, oval, spire rather short, last whorl inflated. Whorls step-like, with tubercles or spines at the angles. Aperture with a small notch anteriorly; outer lip thin. Inferior Oolite to Upper Cretaceous. Ex. *P. nodulata*, Great Oolite.

Littorina. Shell thick, not nacreous internally, turbinate, few-whorled, without umbilicus. Aperture rounded, angular behind, outer lip sharp. Columella flattened. Operculum horny, paucispiral. Lias to present day. Ex. *L. littorea*, Red Crag to present day.

Capulus. Shell conical, with apex bent considerably backward and more or less spirally inrolled. Aperture rounded or irregular. Muscular impression horse-shoe shaped. Palæozoic to present day. Ex. *C. hungaricus*, Coralline Crag to present day.

Platyceras. Allied to *Capulus*; apical part usually more extensively coiled, dextral. Surface smooth, or with concentric striæ, or radial folds or spines. Cambrian to Trias. Ex. *P. cornutum*, Silurian.

Calyptræa. Shell conical, trochiform, spiral, apex central; interior with a spiral plate under the apex and attached at the periphery. Aperture nearly circular. Cretaceous to present day. Ex. *C. chinensis*, Coralline Crag to present day.

Natica. Shell oval, globular, generally smooth, spire short, last whorl very large. Aperture semilunar or oval, entire; outer lip sharp, inner lip thickened with callus, not crenulate. Umbilicus usually present, often filled with callus. Operculum of the same size as aperture, horny or calcareous, paucispiral, nucleus excentric. Trias to present day. Ex. *N. canrena*, Recent; *N. millepunctata*, Coralline Crag to present day. There are numerous sub-genera.

Xenophora (=*Phorus*). Shell conical, low, with flattened or concave base; periphery of last whorl sharp. Aperture large oblique, lower part concave, outer lip sharp and oblique. Umbilicus generally small. Whorls flattened, covered with agglutinated foreign bodies. Cretaceous to present day. Ex. *X. agglutinans*, Barton Beds.

Viviparus (=*Paludina*). Shell thin, turbinate, with a thick periostracum ; whorls convex, smooth or with faint ribs. Umbilicus small or absent. Aperture entire, oval, slightly angular behind. Operculum horny with concentric striæ, and excentric nucleus. Inferior Oolite to present day. Lives in fresh water. Ex. *V. lentus*, Bembridge Beds.

Turritella. Shell without umbilicus, turreted, many-whorled, whorls flat or slightly convex, ornamented with spiral ribs and with striæ of growth ; spire very long and acute. Aperture oval or subquadrate, entire, outer lip thin, slightly produced in front. Operculum horny. Trias to present day. Ex. *T. terebra*, Pliocene to present day ; *T. imbricataria*, Barton and Bracklesham Beds.

Melania. Shell with dark periostracum, elongate, turreted, many-whorled, without umbilicus, apex sharp but usually corroded. Surface smooth, or ornamented with spiral striæ, or transverse ribs, or spines. Aperture entire, narrow behind, rounded in front; outer lip sharp, slightly sinuous behind. Columella smooth. Operculum horny, oval, sub-spiral. Wealden to present day. Lives in fresh water. Ex. *M. amarula*, Recent; *M. acuta*, Bembridge Beds.

Nerinea (fig. 91). Shell elongate, usually without an umbilicus, whorls numerous. Aperture subquadrangular, oval or elongate, with a short anterior canal; outer lip thin, with a posterior slit near the suture, which becomes filled, leaving a continuous band. Columella and also the interior of the whorls furnished with folds which are continuous to the apex. Inferior Oolite to Upper Cretaceous. Ex. *N. cingenda*, Inferior Oolite.

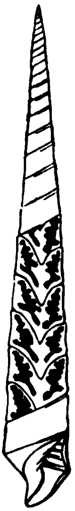

FIG. 91. *Nerinea trachea*, partly sliced to show the form of the interior. Great Oolite. (From Woodward.) × ⅔.

Cerithium. Shell without an umbilicus, turreted, without periostracum.

Whorls numerous, narrow, the last whorl always much shorter than the spire. Aperture oblong or semi-oval, with a short posterior canal and a well-marked recurved anterior canal; outer lip more or less thickened and often somewhat reflected; columella concave. Operculum horny, oval, paucispiral, with submarginal nucleus. Jurassic to present day. Ex. *C. adansoni*, Recent; *C. mutabile*, Barton and Bracklesham Beds. There are several sub-genera[1].

Potamides. Form similar to *Cerithium*. Shell with a brown or blackish periostracum. Aperture rounded or subquadrangular with a short anterior canal; outer lip thin or thickened. Operculum circular, multispiral, with central nucleus. Lives in brackish water. Cretaceous to present day. Ex. *P. funatus*, Woolwich Beds.

Aporrhais. Shell fusiform, without an umbilicus, whorls numerous, spire elongate. Aperture produced into a straight or curved anterior canal. Outer lip expanded, thick with an anterior sinuosity, lobed or digitate, one of the processes being attached to a part of the spire. Operculum small. Jurassic to present day. Ex. *A. pes-pelicani*, Coralline Crag to present day.

Alaria. Similar to *Aporrhais*, but without a process from the outer lip attached to the spire, and without anterior sinuosity. Jurassic and Cretaceous. Ex. *A. armata*, Great Oolite.

Strombus. Shell ovoid, ventricose, tuberculate or spiny, without umbilicus. Spire with several whorls, the last very large. Aperture long, narrow, with a notch or a short canal anteriorly; canaliculate posteriorly; outer lip expanded, wing-like, thick, often lobed, with a notch near the anterior margin. Operculum small, horny, claw-shaped, with serrated edge. Cretaceous to present day. Ex. *S. pugilis*, Recent.

Rostellaria. Shell fusiform, spire elongated, composed of many whorls, which are smooth or faintly ribbed. Aperture oblong, with a long straight or slightly curved anterior canal, and a posterior canal applied to the spire; outer lip expanded, with tooth-like processes, and an anterior notch. Operculum small, oval or claw-shaped, edge not serrated. Eocene to present day. Ex. *R. curta*, Recent; *R. lucida*, London Clay, etc.

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[1] *Cerithium* is also used in a more restricted sense by some authors to include only forms in which the columella is thick and provided with a tooth-like tubercle, the outer lip is expanded in front, and the whorls are provided with varices.

Hippochrenes. Similar to *Rostellaria*, but outer lip wing-like and without processes. Upper Cretaceous and Eocene. Ex. *H. amplus*, Barton Beds.

Rimella. Similar to *Rostellaria*, but with cancellate ornamentation; outer lip but little expanded and reflected outwards. Upper Cretaceous to present day. Ex. *R. rimosa*, Barton Beds.

Cypræa. Shell ovoid or elongate, convex, convolute, surface covered with shining enamel. Spire almost or quite concealed by the last whorl. Aperture oblong and narrow, as long as the shell, with a short canal at each end; outer lip inflected and crenulated; inner lip crenulated. In the young form the outer lip is thin and the spire prominent. Upper Jurassic to present day. Ex. *C. mauritiana*, Recent; *C. oviformis*, London Clay.

Lotorium (= *Triton*). Shell thick, oval or fusiform. Spire elongate, with varices which are continued over a few whorls only. Aperture with a posterior notch, and a slightly curved anterior canal; outer lip thick, crenulate internally; inner lip with callus and usually with folds. Cretaceous to present day. Ex. *L. nodulosum*, Barton and Bracklesham Beds.

Buccinum. Shell oval or elongate, without an umbilicus. Spire long. Whorls ventricose, smooth or with longitudinal folds. Aperture oval, large; outer lip simple, thin; anterior canal short, truncated, a little reflected; columella a little sinuous. Operculum small, oval or circular. Eocene to present day. Ex. *B. undatum*, Coralline Crag to present day.

Nassa. Shell ovate, elongate without umbilicus, generally ornamented. Aperture oval, with a short reflected anterior canal; inner lip with callus, reflected on to the last whorl, with a tooth-like projection near the anterior canal; outer lip thick, crenulate internally. Columella truncated, provided with an oblique fold at its base. Upper Cretaceous to present day. Ex. *N. mutabilis*, Pliocene and living.

Chrysodomus (=*Neptunea*). Shell solid, fusiform or elongate, sometimes sinistral. Aperture oval; outer lip simple; inner lip smooth; anterior canal short, slightly twisted. Operculum horny, unguiculate. Cretaceous to present day. Ex. *C. antiquus*, Red Crag to present day.

Purpura. Shell tuberculate, striated or lamellar, without varices. Spire rather short, last whorl large; no umbilicus. Aperture oval, large, with a short oblique anterior canal, and a posterior notch or groove. Columella flattened, with callus. Operculum lamellar, nucleus marginal. Pliocene to present day. Ex. *P. persica*, Recent; *P. lapillus*, Red Crag to present day.

Murex. Shell oval or elongate, solid, spire prominent and sharp; whorls convex, each carrying three or more varices, which may be spiny, foliaceous, or tubercular. Aperture ovate, anterior canal more or less long, narrow and tubular, often closed; no posterior canal; outer lip thick, inner lip smooth. Operculum oval, nucleus sub-apical. Upper Cretaceous to present day. Ex. *M. brandaris*, Recent; *M. frondosus*, Barton Beds.

Typhis. Similar to *Murex*; small, with hollow spines, and anterior canal completely closed. Upper Cretaceous to present day. Ex. *T. pungens*, Barton Beds.

Fusus. Shell without umbilicus, narrow, fusiform, elongate; spire sharp and many-whorled. Aperture oval; outer lip simple, thin. A long, straight, narrow anterior canal, not closed. Columella smooth, without folds. Operculum oval. Cretaceous to present day. Ex. *F. colus*, Recent; *F. porrectus*, Barton Beds, etc.

Mitra. Shell fusiform, thick. Spire elevated, summit acute. Aperture narrow, elongate, notched in front. Columella with oblique folds, of which the posterior are the stronger; outer lip not reflected, thickened but not grooved internally. No operculum. Eocene to present day. Ex. *M. episcopalis*, Recent; *M. labratula*, Bracklesham Beds.

Voluta. Shell ovate or fusiform, solid, thick, summit of spire mammillated. Last whorl very large, aperture elongate, oval; anterior canal very short, recurved; outer lip simple, often thick, rarely reflected. Columella with oblique folds in front, of which the anterior are the stronger. No operculum. Upper Cretaceous to present day. Ex. *V. muricina,* London Clay and Bracklesham Beds.

Ancilla (= *Ancillaria*). Shell smooth, oval or oblong; last whorl large; sutures usually covered by callus. Aperture elongate, broadening anteriorly, with a small notch near the suture, and a deep sinuosity at the anterior end which is truncated; columella with callus posteriorly, twisted and with folds anteriorly. Cretaceous to present day. Ex. *A. buccinoides*, Bracklesham, Barton, and Headon Beds; *A. cinnamonea,* Recent.

Pleurotoma. Shell turreted, fusiform, spire long and sharp, last whorl long. Aperture oval, elongate; outer lip curved, with a deep slit near the suture; inner lip smooth. Anterior canal long, straight, narrow. Operculum horny, ovate, acute, nucleus apical. Upper Cretaceous to present day. Ex. *P. babylonia,* Recent; *P. dentata,* Bracklesham Beds.

Conus. Shell inversely conical, generally smooth, the last whorl enveloping the greater part of the preceding whorls. Spire short, flattened or conical, many-whorled. Aperture long, narrow, straight, with parallel or sub-parallel borders; outer lip thin, simple, no folds or teeth, notched at the suture. Columella straight, smooth. Operculum horny, much smaller than the aperture. Upper Cretaceous to present day. Ex. *C. marmoreus,* Recent; *C. deperditus,* Bracklesham Beds. There are numerous sub-genera.

The Heteropoda are a group of the Streptoneura which have become modified for a pelagic mode of life. The foot is laterally compressed so as to form a vertical fin. A shell may be absent, but, when present, it is always thin and light. Only a very few forms have been found fossil.

ORDER II. EUTHYNEURA.

The visceral nerve-cord forms (except in *Actæon*) a simple, untwisted loop. One gill only is present. An operculum is generally absent. There are two Sub-Orders, (1) Opisthobranchia, (2) Pulmonata.

SUB-ORDER I. OPISTHOBRANCHIA.

The gill is placed behind the heart; there is one auricle only, which is behind the ventricle. All the Opisthobranchia are marine.

The Opisthobranchia are divided into two groups:—

(1) the *Nudibranchia*, in which there is no mantle, and no shell in the adult; no examples of this division have been found fossil.

(2) the *Tectibranchia*, which usually possess a mantle, a shell, and a true gill. The following three genera are examples of the Tectibranchia.

Actæon. Shell oval, ornamented with spiral pitted striæ or grooves; spire prominent, conical, sharp. Aperture elongate, rounded in front; outer lip sharp; columella with one strong, slightly oblique fold at the anterior end. Cretaceous to present day. Ex. *A. tornatilis*, Coralline Crag to present day.

Avellana. Shell globular, ornamented with spiral striæ or grooves; spire very short. Aperture semi-lunar, curved, entire; outer lip much thickened, reflected externally, dentate internally. Inner lip thickened, with two or three prominent folds. Cretaceous. Ex. *A. incrassata*, Upper Greensand.

Bulla. Shell solid, smooth, sub-globular or ovoid, convolute. Spire concave. Aperture as long as the last whorl, rounded at both ends, widest in front; outer lip sharp. Inner lip with callus. Cretaceous to present day. Ex. *B. ampulla*, Recent; *B. globulus*, London Clay and Bracklesham Beds.

The Pteropods are pelagic gasteropods in which the foot is represented by two lateral wing-like fins, and the head is not well marked; a shell may or may not be present. Pteropods occur in enormous numbers near the surface in the open ocean; and their shells, which are thin and transparent, form a considerable part of the 'pteropod ooze'—one of the deep-sea deposits found in the warmer parts of the Atlantic Ocean.

By some writers the Pteropods have been regarded as a distinct Class of the Mollusca; by others as an Order of the Gasteropoda. Recent work, however, has shown that they agree very closely with the Opisthobranchia, and that they should be regarded as members of that sub-order which have become modified for a pelagic mode of life.

Fossil Pteropods have been found in Upper Cretaceous and Tertiary formations and belong mainly to genera which have living representatives. In the Silurian and Devonian rocks large numbers of small conical smooth shells occur which closely resemble the living form *Styliola* and are probably the remains of Pteropods.

The three genera described below (which are almost confined to Palæozoic deposits) have been considered by many authors to be Pteropods, but they differ from living forms in having much larger and thicker shells, and their affinities must for the present be regarded as uncertain. Some writers have suggested that they may be Polychæte worms, others that they are perhaps Cephalopods. Ruedemann has recently shown that in some cases *Conularia* was fixed to foreign objects by means of a small bell-like structure at the apex of its pyramidal shell; and Verrill has suggested that this form may have been a primitive Dibranch Cephalopod.

Hyolithes (=*Theca*) (fig. 92). Shell straight, rarely curved, pyramidal, triangular in section, smooth or striated; posterior part sometimes crossed by walls. Aperture sometimes oblique; provided with an operculum having the form of a half cone. Cambrian to Permian. Ex. *H. elegans*, Ordovician.

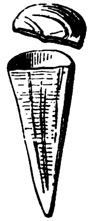

Fig. 92. *Hyolithes* from the Cambrian, showing the operculum. $\times \frac{2}{3}$.

Conularia. Shell thin, generally straight, pyramidal; section quadrangular, each lateral face with a median longitudinal groove; posterior part of shell sometimes provided with concave partitions. Surface ornamented with numerous transverse, parallel, angulated ridges. Aperture partly closed by incurved triangular or lobed processes. Ordovician to Trias. Ex. *C. quadrisulcata*, Carboniferous.

Tentaculites. Shell thick, solid, in the form of a greatly elongated cone, straight or slightly curved; section circular, posterior extremity sharp or with a vesicular enlargement. Surface provided with prominent, transverse, parallel rings, and with transverse and longitudinal striæ. Ordovician to Devonian. Ex. *T. anglicus*, Bala Bèds.

SUB-ORDER II. PULMONATA.

The mantle-cavity is modified to form a lung. There is no gill. The Pulmonata are mainly land and freshwater forms.

Limnæa. Shell spiral, thin, horny; last whorl very large, spire sharp. Aperture large, oval, rounded in front. Columella more or less twisted. Peristome sharp, entire. Purbeck Beds to present day. Lives in fresh water. Ex. *L. stagnalis*, Pliocene to present day; *L. longiscata*, Headon Beds, etc.

Planorbis. Shell discoidal, horny, whorls numerous. Aperture oblique; peristome simple, sharp. Jurassic to present day. Freshwater. Ex. *P. corneus*, Red Crag to present day; *P. euomphalus*, Headon Beds, etc.

Helix. Shell variable—conical, discoidal, or globular; with or without an umbilicus; aperture oblique. Peristome simple or reflected. Eocene to present day. Lives on land. Ex. *H. nemoralis*, Pleistocene and living. There are numerous sub-genera.

Distribution of the Gasteropoda.

Some of the Gasteropoda live on land, others in fresh water, but the majority are marine; they are found in the seas of all parts of the world but are especially abundant in warm regions and in comparatively shallow water. A few forms can exist both on land and in water, *e.g.* *Ampullaria*, which commonly lives in lakes and rivers, and is also found on land. Some marine genera, such as *Littorina*, *Cerithium*, and *Purpura*, are able to live in fresh as well as in salt water; on the other hand some freshwater forms are at times found living in the sea, *e.g.* *Limnæa*, *Neritina*, *Bithynia*, and *Planorbis*; this is especially the case in places where the water is less salt than the main mass of the ocean, as for instance in the Baltic, where we find the genera just mentioned living side by side with *Littorina* and with the marine lamellibranchs *Cardium*, *Tellina*, and *Mya*. Two divisions of the Gasteropoda are entirely marine, viz. the Isopleura and Opisthobranchia; the Streptoneura (or Prosobranchia) are mainly marine. Nearly all the Pulmonata are found on land or in fresh water.

In connexion with the Gasteropoda a few words may be said with regard to the distribution of the marine Mollusca generally. Some forms live in mid-ocean at or near the surface; these include the Pteropods, the Heteropods and a few other Gasteropods, as well as many Dibranchiate Cephalopods. Others live on the sea-bottom and are found at almost all depths, but are much more abundant in shallow than in deep water. The deep-sea species have a wide geographical range, owing to the uniformity of the conditions under which they live. The Mollusca which occur in moderate depths have a smaller range and are distributed in regions or provinces, limited mainly by conditions of climate. Each province is marked by the abundance of certain genera and by the presence of some species which do not extend into other provinces; but they are not separated by any sharp line, and very few genera are confined to any one province. In the European region the chief provinces[1] are: the *Arctic*, which includes the polar seas and extends as far south as the north of Iceland and the North Cape; the *Boreal*, extending from the last, down to near the southern end of Norway and including the Shetland Islands; the *Celtic*, including the coasts of Southern Sweden, the Baltic, Denmark, Northern France and the British Isles; and the *Lusitanian*, comprising the coasts of the Bay of Biscay, Portugal, the Mediterranean, and North-west Africa. In each province the character of the molluscan fauna also varies with the nature of the sea-bottom, some genera (*e.g. Mya, Lutraria, Scrobicularia*) being found especially on muddy bottoms, others (*e.g. Natica, Turritella, Cypræa, Cardium*) on sandy, and yet others (*e.g. Buccinum, Littorina, Patella, Arca*) on rocky.

The distribution of the Mollusca varies also with the depth of the sea, due to temperature (which as a whole decreases with the depth), to pressure, and to the gradual disappearance of light; in this respect five zones have been traced:—

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[1] For a map of the provinces see Woodward's *Manual of the Mollusca*, or Fischer's *Manuel de Conchyliologie*.

(1) *Littoral Zone,* extending between high and low water marks; in Europe this is especially characterised by the abundance of the genera *Littorina, Trochus, Patella, Hydrobia, Haliotis, Fissurella, Solen, Mya, Donax,* and *Cardium.*

(2) *Laminarian Zone,* ranging from low water down to about 14 fathoms; in it algæ (*Laminaria,* etc.) are particularly luxuriant, and afford food for numerous phytophagous mollusks. Some of the commonest genera met with are *Trochus, Nassa, Rissoa,* and *Ostrea.* Nudibranchs are also very numerous.

(3) *Zone of Nullipores or Corallines,* from 14 to about 35 fathoms, where the calcareous algæ (Corallinaceæ) are very abundant. It is characterised by the abundance of *Pleurotoma, Fusus, Chrysodomus, Buccinum, Natica, Eulima, Venus, Dosinia, Astarte, Nucula, Arca, Lima,* and *Pecten.*

(4) *Zone of Brachiopods and deep-sea Corals,* from 35 to about 230 fathoms; off Europe *Oculina* is the common coral; Brachiopods and Polyzoa are abundant. Some of the chief molluscs are *Turritella, Odostomia, Dentalium, Tellina, Cuspidaria* (= *Neæra*), and *Yoldia.*

(5) *Abyssal Zone,* extending from the preceding down to the greatest depths at which life has been found. In this zone the shells are mostly thin, colourless, transparent, and of small size; it is especially characterised by numerous Scaphopods; other common forms are *Pleurotoma, Fusus, Actæon, Scaphander, Philine, Arca, Nucula, Limopsis, Nuculana* (= *Leda*), *Lima,* and *Pecten.* The remains of Pteropods which have fallen from the surface of the ocean after death are often numerous.

In the fossil state gasteropods are less abundant than lamellibranchs, although they exceed them at the present day. The earliest forms occur in the Lower Cambrian (*Olenellus* Beds) and are referred to the genera *Scenella, Stenotheca, Platyceras,* and *Raphistoma.* Throughout the Palæozoic formations the holostomatous Streptoneura are the predominating forms; no gasteropods with well-developed siphons are known to occur until the Trias is reached, but siphonostomatous genera become abundant in the Oolites, still more so in the Cretaceous, and in the Tertiary they are the principal forms. The other divisions are not nearly so well represented as the Streptoneura. The Isopleura range from the Ordovician to the present day, but are rare as fossils. The Heteropoda are represented by a few forms only, the first occurring in the Miocene. The Opisthobranchia range from the Carboniferous to the present day; they are moderately well represented in the Jurassic and Cretaceous formations, and become more abundant in the Tertiary. The Pulmonata are first found in the Carboniferous, but they are rare until the Tertiary is reached. Forms which have been regarded as Pteropods occur in the Lower Cambrian, and also in later Palæozoic formations, but, as already mentioned, the affinities of some of these (*Hyolithes, Conularia, Tentaculites*) are somewhat doubtful; a more probable representative of the Pteropods (closely resembling the living *Styliola*) occurs in the Silurian and Devonian. Undoubted remains of Pteropods are found in the Upper Cretaceous and later formations.

The most important genera of Gasteropoda found in the different systems are:—

Cambrian. *Scenella, Platyceras, Raphistoma, Bellerophon, Straparollina, Ophileta, Hyolithes, Conularia.*

Ordovician. *Bellerophon, Holopæa, Cyclonema, Maclurea, Conularia, Tentaculites.*

Silurian. *Pleurotomaria, Murchisonia, Bellerophon, Euomphalus, Omphalotrochus, Holopæa, Cyclonema, Holopella, Platyceras, Conularia.*

Devonian. *Pleurotomaria, Murchisonia, Bellerophon, Loxonema, Euomphalus, Macrochilina, Tentaculites.*

Carboniferous. *Pleurotomaria, Murchisonia, Bellerophon, Loxonema, Euomphalus, Naticopsis, Macrochilina, Conularia.*

Permian. *Pleurotomaria, Murchisonia, Loxonema, Macrochilina.*

Trias. *Pleurotomaria, Trochus, Loxonema, Scala* (=*Scalaria*), *Naticopsis, Natica, Turritella.*

Jurassic. *Pleurotomaria, Amberleya, Cirrus, Trochus, Natica, Pseudomelania, Bourguetia, Nerinea, Cerithium, Alaria, Malaptera, Purpurina, Purpuroidea.*

Cretaceous. *Pleurotomaria, Solarium, Turritella, Natica, Viviparus* (=*Paludina*), *Cerithium, Scala* (=*Scalaria*), *Aporrhais, Avellana.*

Eocene. *Xenophora* (=*Phorus*), *Calyptræa, Natica, Melanatria, Turritella, Cerithium, Rostellaria, Hippochrenes, Rimella, Aporrhais, Cypræa, Cassis, Cassidaria, Lotorium* (=*Triton*), *Fusus, Pisania, Pyrula, Murex, Typhis, Voluta, Oliva, Ancilla* (=*Ancillaria*), *Cancellaria, Pleurotoma, Conus.*

Oligocene. *Nerita, Neritina, Natica, Viviparus* (=*Paludina*), *Melania, Melanopsis, Cerithium, Potamides, Murex, Fusus, Ancilla, Pleurotoma, Limnæa, Planorbis, Rissoa, Helix, Amphidromus.*

Pliocene. *Emarginula, Trochus, Scala, Turritella, Natica, Littorina, Capulus, Cerithium, Buccinum, Liomesus* (=*Buccinopsis*), *Tritonofusus, Chrysodomus, Nassa, Purpura, Fusus, Pleurotoma, Actæon.*

CLASS III. SCAPHOPODA.

The Scaphopoda include only a few genera, which in some respects resemble the lamellibranchs, and in others the gasteropods. The body is elongated, and bilaterally symmetrical. The mantle is cylindrical and open at both ends; it secretes a straight or slightly curved tubular shell which is also open at both ends. The foot is greatly elongated and can be protruded through the larger aperture of the mantle and shell. The animal is attached to the posterior part of the shell by means of a muscle; an odontophore is present, but the head is not well marked, and eyes, gills, and heart are absent. The sexes are separate. All the scaphopods are marine, and they often live buried in sand or mud; some species occur at great depths. The earliest forms are found in the Ordovician rocks.

Dentalium. Shell conical or sub-cylindrical, tapering posteriorly, slightly curved. Anterior aperture simple, not constricted; posterior aperture smaller, without a fissure. Surface ornamented with longitudinal striæ or ribs. Eocene to present day. Ex. *D. elephantinum*, Recent. Forms closely allied to *Dentalium* occur in many Palæozoic and Mesozoic formations.

CLASS IV. CEPHALOPODA.

The Cephalopods are entirely marine and are more highly organised than any of the other molluscs; well-known living forms are the cuttle-fishes, the squids, the paper-nautilus and the pearly nautilus, whilst amongst extinct types are belemnites, ammonites, and goniatites. Existing forms are always bilaterally symmetrical. The head is well marked and is separated from the body by a constriction; it is especially characterised by the presence of a circle of arm-like or lobe-like processes around the mouth (fig. 93 *e*, *f*); these processes are provided either with sucking-discs or with tentacles, and are used for seizing food and in locomotion. Behind the head is a muscular tube termed the *funnel* (*d*), which opens in front to the exterior, and behind into the mantle-cavity (*c*); this may be either a perfect tube or may be formed by the apposition of two trough-like lobes. By some authors the arms or lobes around the mouth are regarded as the fore-foot, and the funnel as the mid-foot, the hind-foot being absent. Others, however, consider that the funnel alone represents the foot. The name *Cephalopoda* is due to the former view—that the foot has grown round the mouth and is divided up into arms or lobes. The part of the body near the mouth and funnel is regarded as the ventral surface, and the opposite end as dorsal.

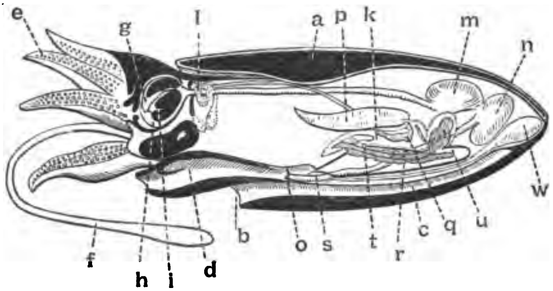

Fig. 93. Diagram of a vertical median antero-posterior section of *Sepia officinalis*. *a*, shell; *b*, mouth of mantle-cavity; *c*, mantle-cavity; *d*, funnel; *e*, arms; *f*, long arm; *g*, the upper beak or jaw; *h*, the lower beak or jaw; *i*, odontophore; *k*, the viscero-pericardial sac; *l*, the nerve-collar; *m*, the crop; *n*, the gizzard; *o*, the anus; *p*, left gill; *q*, ventricle of the heart; *r*, renal glandular mass; *s*, left nephridial aperture; *t*, viscero-pericardial aperture; *u*, branchial heart; *w*, ink-sac. (After Lankester.)

On the upper surface of the head there are two large eyes, which, except in *Nautilus*, are almost as highly developed as in vertebrate animals. The mantle is formed by a single fold of the skin, which passes quite round the body of the animal; on the anterior (upper) surface the fold is very shallow so that the mantle-cavity exists mainly on the posterior (under) surface. The feather-like gills (*p*) are placed in the mantle-cavity; in the Dibranchs (cuttle-fishes, etc.) there is one pair, in *Nautilus* there are two. A current of water flows in at the sides of the mantle-cavity, and can be forced out through the funnel by means of the contraction of the walls of the mantle-cavity. In the Dibranchiate Cephalopods there is a gland, known as the *ink-sac* (*w*), which secretes a black fluid (sepia); the duct from this gland opens with the anus (*o*) into the mantle-cavity; the ink is ejected at times and passes out through the funnel, rendering the water cloudy, and by this means facilitating the escape of the animal from its enemies. Just within the mouth there are two jaws (*g, h*) which have the form of a parrot's beak, and are either horny or calcareous. An odontophore (*i*) is also present, but the arrangement of the teeth is less variable than in the gasteropods, and is of little value for systematic purposes.

The heart consists of a median ventricle (*q*), and of lateral auricles, which are either two or four in number, according as there are two or four gills; it gives off in front an artery to the head, and one behind to the viscera. The nervous system is remarkable in that the ganglia are placed close together, forming a central mass (*l*); one part is placed above the œsophagus, and is connected by cords with the other part beneath it. This central nervous system is covered by a cartilaginous ring and gives off nerves to the arms, viscera, etc. The sexes of the Cephalopods are always separate, and the genital ducts open into the mantle-cavity. In some forms there is no shell;

but when present it may be external (fig. 94) or internal (fig. 93 *a*); in the latter case it is usually placed in a sac in the mantle on the antero-dorsal side. The Cephalopoda are divided into two Orders:—(1) Tetrabranchia, (2) Dibranchia.

ORDER I. TETRABRANCHIA.

The Tetrabranchia have four gills, and an external chambered shell. There are two Sub-Orders, (1) Nautiloidea, (2) Ammonoidea.

SUB-ORDER I. NAUTILOIDEA.

In Palæozoic times the Nautiloid Cephalopods were very abundant, but at the present day the only representative of the group is *Nautilus*. *Nautilus* possesses two pairs of gills, two pairs of auricles, and two pairs of

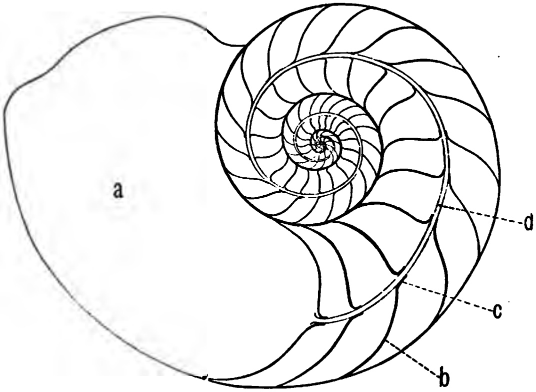

FIG. 94. Section of the shell of *Nautilus pompilius*, Recent. *a*, body-chamber; *b*, septum; *c*, septal neck; *d*, siphuncle. × $\frac{1}{3}$.

kidneys. An ink-sac is absent; the funnel is not a complete tube, but is formed of two parts. Around the mouth are numerous lobe-like processes which are given off from the margin of the head; these do not bear suckers, as is the case in the Dibranchs, but tentacles which can be retracted within sheaths. The jaws are calcified and are not uncommonly found fossil.

A shell is present in all Nautiloids and is always external; it consists of a tube, which tapers to a point at one end, and may be straight, arched, or spiral; in the spiral forms the whorls may be separate, or partly free, or in contact throughout; in some cases they are placed all in one plane, in others they are arranged in a helicoid spiral. The cavity of the shell, unlike that in most gasteropods, is not continuous throughout from the aperture to the apex, but is divided up into a number of chambers by means of partitions termed *septa* (fig. 94 *b*); the size of the chambers increases towards the aperture of the shell. The body of the animal is placed in the last chamber (*a*), to the walls of which it is attached by muscles; on the inner side of the whorl, next the last septum, are two oval muscles which leave faint impressions on the shell; these muscles are connected both above and below by a band of fibres called the *annulus*, which also leaves a mark on the shell. In *Nautilus* the funnel is placed at the external margin of the aperture, so that this part of the last chamber is regarded as ventral.

It is usually stated that all the earlier chambers are filled with air only, but according to some writers they contain liquid. Originally, of course, the animal lives in the earlier part of the shell, but as growth goes on, it successively withdraws towards the aperture, each time depositing behind it a septum and thus forming a new chamber. All the chambers are traversed by a tube known as the *siphuncle* (*d*), which is given off from the dorsal end of the body. The position of the siphuncle varies in different genera; in *Nautilus* it pierces the septa at or near their centres; in others it may be near the external margin or near the internal margin of the whorl. In the modern *Nautilus* the siphuncle is membranous, except that it is coated with calcareous granules; but in most fossil Nautiloids it was completely invested by a calcareous tube. The interior of the siphuncle is frequently partly filled up with calcareous deposits. The septa are often prolonged in the form of funnels around the siphuncle, so as to more or less completely insheath it. These funnels are termed *septal necks* (*c*); in nearly all the Nautiloidea they are directed backwards.

The aperture of the shell has, in some cases, a simple margin, being either straight or slightly curved; in others, processes may be given off from the external margin or from the sides; in *Nautilus* there is a sinus at the external margin where the funnel occurs. In a few forms (*e.g.* *Gomphoceras*, fig. 96) the aperture is constricted. The line where the edge of the septum unites with the outer or tubular part of the shell is known as the *suture*; obviously this will only be seen when the shell is removed; but fossil forms frequently occur as casts and in these the sutures are admirably shown. One of the chief characters of the shell in the Nautiloidea is the simple form of the sutures; usually they are either straight or only slightly undulating.

The shell which covered the embryo in the Cephalopoda is known as the *protoconch*[1]; in the Nautiloidea this is seldom preserved, probably on account of its delicate nature. If the shell of a *Nautilus* be sliced in two there will be seen at the centre a space which was probably occupied by the protoconch. At the apex of the first chamber will be found an opening which is usually slit-like and surrounded by either a rim or a depression; this opening probably served to connect the protoconch with the first chamber. The siphuncle commences in the first chamber as a closed tube. In a few specimens of *Orthoceras* indications of the protoconch have been found at the apex of the shell.

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[1] This corresponds to the protegulum of the Brachiopods and to the prodissoconch of the Lamellibranchs.

Orthoceras. Shell straight or occasionally slightly curved, conical; transverse section usually circular. Septa simple, concave; body-chamber large; aperture not contracted or produced into lobes. Siphuncle usually slender, cylindrical, and central, but sometimes sub-central or ex-central. Ornamentation variable. *Orthoceras* is divided into several sub-genera. Tremadoc Beds to Trias. Ex. *O. annulatum*, Wenlock Limestone; *O. goldfussianum*, Carboniferous Limestone.

Actinoceras (fig. 95). Similar to the preceding, but the siphuncle is large and is inflated between the septa so that each segment is spheroidal, and contains in the interior a large amount of calcareous deposit. In the centre of the siphuncle is a small tube known as the *endosiphon* (*d*), from which radiating tubes (*c*) are given off between the septa and pass to the siphuncle. Ordovician to Carboniferous Limestone; in England chiefly Carboniferous. Ex. *A. giganteum*, Carboniferous Limestone.

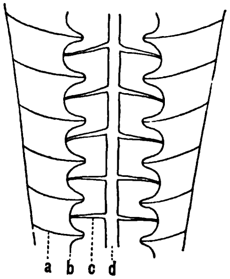

FIG. 95. Diagrammatic section of a portion of the shell of *Actinoceras*. *a*, septum; *b*, siphuncle; *c*, canals from endosiphon; *d*, endosiphon.

Gomphoceras (fig. 96). Shell oval, short, straight or slightly curved; section nearly circular; body-chamber very large, aperture contracted, T-shaped. Septa close together. Siphuncle sub-cylindrical or beaded, sub-central, placed nearer the more convex side of the shell. Surface smooth or with transverse ribs or striæ. Silurian (perhaps also Ordovician, Devonian and Carboniferous). Ex. *G. ellipticum*. Lower Ludlow.

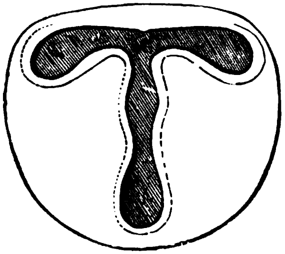

FIG. 96. Aperture of *Gomphoceras bohemicum* from the Silurian. (From Woodward.) Natural size.

Phragmoceras. Similar to the last (by some authors included in it) but curved, rapidly increasing in diameter, laterally compressed, section oval; siphuncle near the inner (concave) margin. Silurian. Ex. *P. broderipi*.

Ascoceras. Shell a little curved; the earlier part (which is rarely found) is like *Orthoceras*, but with the septa more widely separated. The later formed part is sac-like and a little more convex on the outer than on the inner side; the body-chamber occupies most of the outer side; the septa join together and then bend round and divide again before reaching the inner side of the shell; the siphuncle of this part is very short. Ordovician, but chiefly Silurian. Ex. *A. bohemicum*, Silurian.

Cyrtoceras. Similar to *Orthoceras* but always curved: never forming a complete volution; section usually elliptical or oval. Siphuncle small, cylindrical or bead-like, usually sub-marginal and usually near the convex side of the shell. Cambrian to Carboniferous. Ex. *C. lineatum*, Devonian.

Poterioceras. Shell fusiform, slightly curved, inflated in the middle, contracted at both ends, but especially at the apical end. Section elliptical in the adult. Siphuncle sub-central or marginal, inflated between the septa. Last chamber large, aperture simple, contracted. Ordovician to Carboniferous. Ex. *P. fusiforme*, Carboniferous Limestone.

Nautilus (fig. 94). Shell more or less globose, spiral, whorls few, coiled in one plane, and more or less embracing. Umbilicus usually small or absent. Last chamber much larger than the preceding one, aperture simple, with an external sinus. Septa concave, sutures more or less undulating. Siphuncle central or sub-central, septal necks short and directed backwards. Surface of shell smooth or ornamented with striæ or ribs. Trias[1] to present day. Ex. *N. pompilius*, Recent; *N. pseudolineatus*, Inferior Oolite.

Discites (=*Discitoceras*). Shell spiral, compressed, discoidal; whorls quadrangular, increasing in size gradually, sometimes a little embracing, with the external margin flat or grooved. The last part of the shell is separated from the preceding whorl for a short distance. Carboniferous Limestone. Ex. *D. compressus*.

Aturia. Shell discoidal, whorls compressed, completely embracing, with rounded external margin; suture-line zigzag, with a deep angular lobe on each side. Siphuncle on the internal margin; septal necks very long, completely covering the siphuncle. Eocene and Miocene. Ex. *A. zic-zac*, London Clay.

SUB-ORDER II. AMMONOIDEA.

The Ammonoids are quite extinct and include the ammonites, goniatites, etc. The shell is generally coiled into a plane spiral, and as a rule the sutures show complicated patterns (fig. 97). The siphuncle is placed at the margin of the shell—usually at the outer, but occasionally at the inner margin; and it does not contain internal calcareous deposits. The septal necks in most of the ammonites are directed forwards, except on some of the earliest septa; in *Clymenia*, on the other hand, they point backwards as in the Nautiloids; and in the goniatites a small collar-like part projects in front of the septum, but the main part of the septal neck extends backwards.

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[1] The species found in the Palæozoic formations which have usually been regarded as constituting sub-genera of *Nautilus* (*e.g. Discites*, *Pleuronautilus*, *Cœlonautilus*, *Temnocheilus*) are considered by recent writers to be distinct genera.

The form of the sutures varies considerably in different genera and is of great importance for systematic purposes.

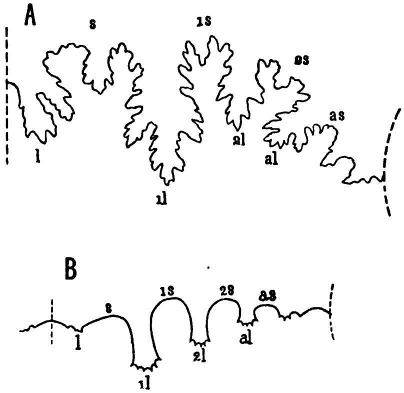

FIG. 97. *A*, suture of an Ammonite (*Parkinsonia parkinsoni*) from the Inferior Oolite. *B*, suture of *Ceratites nodosus*, from the Muschelkalk. *l*, external lobe; 1 *l*, 2 *l*, superior and inferior lateral lobes; *al*, auxiliary lobes; *s*, external saddle; 1 *s*, 2 *s*, superior and inferior lateral saddles; *as*, auxiliary saddles. In each case the straight line on the left represents the position of the siphuncle, and the curved one on the right the line of contact with the next whorl.

The central part of each septum is flattened or slightly curved, but the edges become folded or even frilled, often giving rise to very complex sutures; by this means greater support is afforded to the outer tubular part of the shell than is the case in the Nautiloids where the sutures are simple. The portions of the suture which are convex towards the mouth of the shell are termed the *saddles* (fig. 97 *s*), while the intervening concave portions are known as the *lobes* (*l*). In many forms the lobes and saddles exhibit secondary foldings, which may be slight, producing merely a denticulate structure, or may be deep and provided with other smaller foldings, giving a foliaceous appearance to the suture. The lobes and saddles are similar on the two sides of the shell: commonly there is first the external lobe (fig. 97 *l*) at the external margin, then the superior and inferior lateral lobes (1 *l*, 2 *l*), and near the inner margin other lobes known as auxiliary lobes (*al*) may occur; on the internal margin (opposite to the external lobe) is the internal lobe. The saddles are arranged in a similar manner; there are the external saddle (*s*), the lateral saddles (1 *s*, 2 *s*), and auxiliary saddles (*as*). The form of the successive sutures remains practically constant on the adult part of the shell, but on the younger parts the sutures are less complex. The suture of the first septum may be straight or only slightly curved, as in the Nautiloids; or it may show a broad external saddle; or a narrow external saddle with a lateral lobe on each side. In the second and later septa the sutures become successively more folded, until the adult form is attained.

The protoconch of the Ammonoids, unlike that of the Nautiloids (p. 246), is often preserved; it is formed of calcareous material and is spherical or ovoid in shape. The siphuncle commences in the first chamber of the shell.

In the last chamber of some ammonites and goniatites, and in *Baculites* and *Scaphites*, a pair of calcareous plates, known as the *aptychus* (fig. 98), are occasionally found; in shape they are triangular or nearly semicircular; the margins where the two plates are in contact are straight, the others curved. Since in one ammonite an aptychus

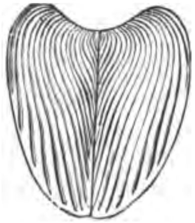

FIG. 98. Aptychus of an ammonite, from the Oxford Clay. (From Woodward.)

was found closing the aperture of the shell, it is probable that it is an operculum (p. 220). A similar structure, but consisting of chitin, and with the two plates united, is sometimes found in the last chamber of ammonites.

When the shell is coiled in a plane spiral, its appearance depends mainly on whether the later whorls grow round the earlier, or are simply in contact with them; in some genera (fig. 102) the last whorl completely conceals all the previous ones, but in others (fig. 104) all the whorls are visible. In the latter case the umbilicus—which in these forms is present on both sides of the shell—is very large. The surface of the shell may be smooth or ornamented with striæ, ribs, tubercles, or spines. In some of the ammonites (fig. 107) the external margin of the shell is provided with a ridge or *keel,* and in these forms the ribs of the two sides are not continuous. The keel may be smooth or toothed. The aperture of the shell is frequently produced into lobes at the sides, or into a pointed projection at the external margin (figs. 107, 108).

The character of the ornamentation varies at different periods in the life of the individual, and by examining the early parts of the shell it is possible to trace out the changes which occurred during growth, from the embryonic protoconch up to the adult. From a study of these changes which take place during development (ontogeny) some authors have attempted to trace out the phylogeny of various types of Ammonoids (see page 13). As in the case of the Brachiopoda (p. 160) it has been found that some forms, which in the adult state appear to be identical, have passed through different stages in development, suggesting that they have descended from different ancestors. Similarly, as already mentioned, changes may be seen in the form of the sutures when traced from the beginning of the first whorl to later parts of the shell. These changes have also been used in the endeavour to work out the phylogeny of Ammonoids, and it has been suggested that different groups of ammonites have descended from various types of goniatites.

Since the Ammonoids are extinct and their soft parts unknown it is impossible to determine what number of gills they possessed; consequently their reference to the Tetrabranchia cannot be definitely established. As, however, the shell agrees closely in structure with that of the Nautiloids, and the animal lived in the last chamber, to which it was fixed by muscles having similar forms and positions to those found in *Nautilus*, we may regard the Ammonoids as most probably Tetrabranchs. The protoconch, however, differs from that of the Nautiloids and presents some resemblance to the protoconch of certain Dibranchs (page 264).

Clymenia. Shell discoidal; whorls numerous, more or less flattened, all visible, but each partly embracing the preceding one; the last chamber is long, generally occupying three-quarters of the last whorl. Aperture with a sinus at the external margin. Sutures with a simple wavy or angular lateral lobe, a lobe at the internal margin (below the siphuncle) and a saddle at the external margin. Siphuncle on the internal margin; septal necks directed backwards. Surface usually ornamented with transverse striæ. Upper Devonian. Ex. *C. lævigata*, *C. undulata*, *C. speciosa.*

Anarcestes[1]. Shell almost discoidal, with a wide umbilicus, and broad, rounded external margin. Body-chamber long; aperture with a deep external sinus. Sutures very simple; the external lobe funnel-shaped and not divided by a saddle; lateral lobe very flat. Siphuncle[2] at the external margin; septal necks long, directed backwards. Body-chamber long. Devonian. Ex. *A. plebeius*, Lower and Middle Devonian.

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[1] This and the two following, with several other genera, have usually been grouped together under the name *Goniatites*; but the differences exhibited by these forms (especially in their sutures) are so great that they can no longer be regarded as belonging to one genus.

[2] In all the following genera the siphuncle has this position.

Glyphioceras (fig. 99). Shell smooth or striated, whorls generally large and embracing, with rounded external margin; umbilicus small or absent. Septal necks short, directed backwards but usually also with a small part projecting forwards. External lobe divided by a saddle; external saddle narrow; lateral lobe angular and deep; lateral saddle broad, rounded, and undivided. Carboniferous. Ex. *G. sphæricum*, *G. crenistria*, Carboniferous Limestone.

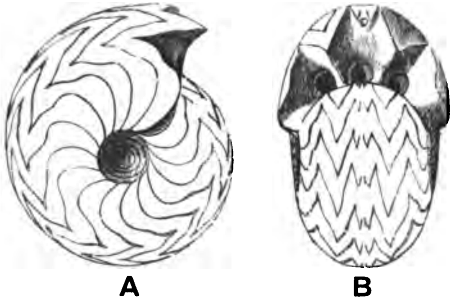

FIG. 99. *Glyphioceras sphæricum*, from the Carboniferous Limestone. The shell has been dissolved exposing the sutures. *A*, side view. *B*, view showing aperture with the siphuncle at the external (upper) margin. (From Woodward.) × 2/3.

Prolecanites. Shell smooth or striated, flattened, with a large umbilicus. Lobes and saddles numerous. External lobe not divided; lateral lobes sharp; lateral saddles narrow and rounded. Devonian and Carboniferous. Ex. *P. compressus* (=*henslowi*), Carboniferous Limestone.

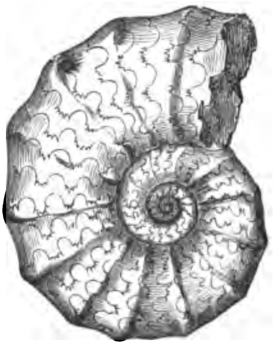

FIG. 100. *Ceratites nodosus*, from the Muschelkalk. The shell has been removed, exposing the sutures. × 1/2.

Ceratites (figs. 97 *B*, 100). Shell discoidal, with ribs or tubercles on the sides, external margin broad; umbilicus large; body-chamber short. Saddles rounded, lobes denticulate; external lobe broad and short. Trias, especially Muschelkalk. Ex. *C. nodosus*, Muschelkalk.

Trachyceras[1]. Shell flattened, highly ornamented with ribs which bear tubercles or spines arranged in spiral rows; at the external margin is a groove; umbilicus generally small. Body-chamber short. Sutures simple, lobes and saddles toothed. Trias. Ex. *T. aon.*

Oxynoticeras. Shell much flattened; umbilicus small; external margin sharp or keeled; surface smooth or striated. Sutures not deeply divided; external saddle large, divided; auxiliary lobes present. Lias to Lower Cretaceous. Ex. *O. oxynotum*, Lower Lias.

Amaltheus. Shell flattened, provided with a keel, which is usually toothed but sometimes sharp; umbilicus generally small; surface smooth. Aperture with a long process at the external margin. Lobes and saddles deep and much divided, with several auxiliary lobes. Jurassic. Ex. *A. margaritatus*, Middle Lias.

Cardioceras (fig. 101). Form similar to the last. Shell with strong curved ribs which bifurcate, and bend forward near the external edge joining the notched keel. Internal lobe with a single point. Kellaways Rock and Oxfordian. Ex. *C. cordatum*, Oxfordian.

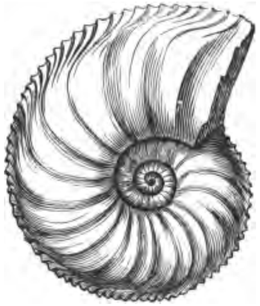

FIG. 101. *Cardioceras cordatum*, from the Oxfordian. × $\frac{5}{6}$.

Arcestes. Shell smooth or striated, nearly globular, with thick whorls; umbilicus small or absent; aperture without lateral projections; body-chamber very long. Lobes and saddles numerous and foliaceous, arranged in a straight row and gradually decreasing in size from the external to the internal margin; there are two lateral lobes and many auxiliary lobes. Trias. Ex. *A. intuslabiatus.* Upper Trias.

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[1] This and the following genera, which are coiled in a plane spiral, and have the siphuncle external, with the septal necks usually directed forwards in the adult, were formerly regarded as constituting a single genus—*Ammonites*. The genera now adopted are founded mainly on the form and ornamentation of the shell, the character of the sutures, and the length of the body-chamber.

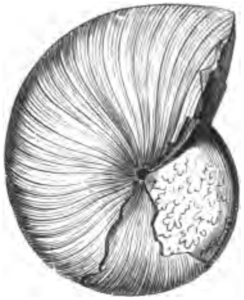

FIG. 102. *Phylloceras heterophyllum*, from the Lias. A part of the shell has been removed to expose the sutures. × ½.

Phylloceras (figs. 102, 103). Shell smooth or with fine striæ or gentle folds (never with tubercles); external margin rounded; umbilicus very small or absent. Saddles and lobes numerous; saddles divided, the extremities being rounded; auxiliary lobes numerous. Jurassic to Cretaceous. Ex. *P. heterophyllum*, Upper Lias.

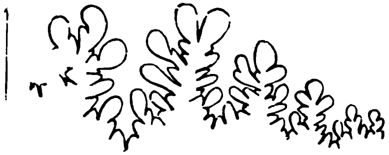

FIG. 103. Suture line of *Phylloceras heterophyllum*, from the Lias. The arrow indicates the position of the siphuncle and points towards the aperture of the shell. (From Woodward.) Natural size.

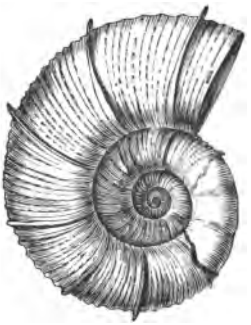

FIG. 104. *Lytoceras fimbriatum*, from the Middle Lias. × ½.

Lytoceras (fig. 104). Shell ornamented with ribs, and often with laminar projections (varices) placed at intervals. Whorls rounded, and only slightly or not at all embracing; aperture usually simple. Suture-line deeply and finely divided, consisting of an external lobe, two lateral lobes, and a narrow internal lobe; of an external saddle and two lateral saddles. The lateral lobes and saddles nearly or quite symmetrically divided. Lias to Cretaceous. Ex. *L. fimbriatum*, Middle Lias.

Hamites. Shell bent upon itself three times, the parts not in contact; the last chamber long. Suture-line similar to *Lytoceras*, with the lateral lobes deeply divided. Surface smooth, or ornamented with ribs, tubercles, or spines. Lower Greensand to Chalk. Ex. *H. maximus*, Gault.

Macroscaphites (fig. 105). Similar to *Lytoceras*. Discoidal; whorls only slightly embracing, the last produced and then bent back in the form of a hook. Lower Cretaceous. Ex. *M. ivani*, *M. gigas*, Lower Cretaceous.

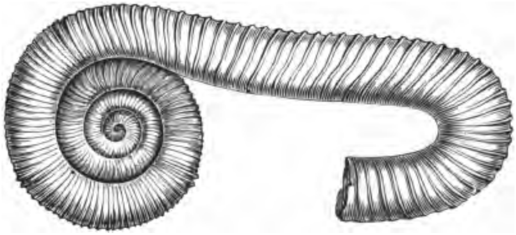

Fig. 105. *Macroscaphites ivani*, from the Lower Cretaceous. × $\frac{1}{6}$.

Turrilites. Shell spiral, turreted, usually sinistral, all the whorls in contact. Sutures similar to *Lytoceras*. Surface ornamented with ribs or tubercles. Gault to Chalk. Ex. *T. costatus*, Chalk.

Baculites. Shell straight (except a small spiral part at the apex, which is the first-formed part of the shell), elongate-conical, elliptical in section; last chamber large, aperture produced at the outer (siphonal) margin. Sutures with the lobes symmetrically divided. Upper Cretaceous. Ex. *B. vertebralis* (=*faujasi*), Chalk.

Psiloceras. Shell discoidal, umbilicus large; whorls increasing in size very slowly, external border rounded or with a very small keel; surface smooth or striated, occasionally with ribs. Body-chamber large. Sutures not much divided. Lower Lias. Ex. *P. planorbe*.

Arietites. Shell discoidal, umbilicus large, whorls numerous, only slightly embracing; with the external border flattened and provided with a keel having a groove on each side of it. Surface with strong simple ribs, which are straight or bent near the margin, and may bear tubercles. Body-chamber occupying from one to one and a quarter whorls. Sutures much divided, with two lateral lobes and one auxiliary lobe. Lower Lias. Ex. *A. bisulcatus.*

Schlotheimia. Shell flat, discoidal, umbilicus usually large. Ribs strong, curved, often bifurcated in the adult, bending forward at the external margin, where they meet at an angle, but are often interrupted by a slight furrow or smooth band at the margin. Sutures deeply divided; superior-lateral lobe generally deeper than the external lobe; three or four auxiliary lobes. Lower Lias. Ex. *S. angulata.*

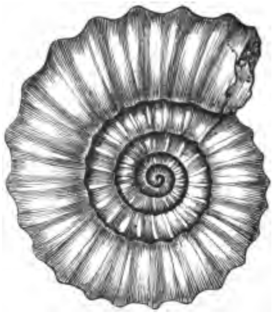

Fig. 106. *Ægoceras capricornum,* from the Middle Lias. × ½.

Ægoceras (fig. 106). Shell discoidal, with a large umbilicus; whorls rounded without a keel, ornamented with simple ribs which are continuous over the external margin. Lobes much divided; superior-lateral lobe larger than the others. Lias. Ex. *Æ. capricornum,* Lower and Middle Lias.

Harpoceras (fig. 107). Shell flattened, with a prominent even keel having a shallow furrow on each side; umbilicus small or of moderate size. Sides of shell with sickle-shaped undivided ribs. Aperture with projections. Sutures strongly divided; superior-lateral lobe deep. Lias. Ex. *H. serpentinum,* Middle and Upper Lias.

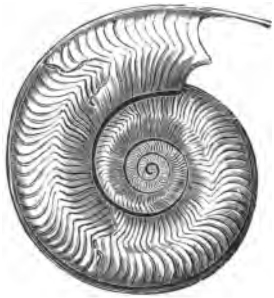

Fig. 107. *Harpoceras serpentinum,* from the Upper Lias. × ⅛.

Hildoceras. Similar to the last. Whorls low, subquadrate in section, with broad external margin and usually a deep furrow on each side of the keel. Umbilicus wide. Ribs distinctly sickle-shaped in most cases. Upper Lias and base of Inferior Oolite. Ex. *H. bifrons.*

Dactylioceras. Whorls numerous, only a little embracing, without a keel; umbilicus large. Ribs numerous, at first straight, afterwards bifurcating, continued over the external margin; without tubercles. Body-chamber long. Sutures moderately divided; external lobe larger than the superior-lateral. Upper Lias and lower part of Inferior Oolite. Ex. *D. commune*, Upper Lias.

Stepheoceras (=*Stephanoceras*) (fig. 108). Whorls thicker than high, external margin rounded, without a keel. Umbilicus large. Surface with straight ribs, which bifurcate on the sides of the whorls and often bear tubercles where they bifurcate. Body-chamber long. Aperture often with lobes. Sutures deeply divided; external lobe large; inferior-lateral lobe and auxiliary lobes small. Inferior Oolite to Oxfordian. Ex. *S. humphriesianum*, Inferior Oolite.

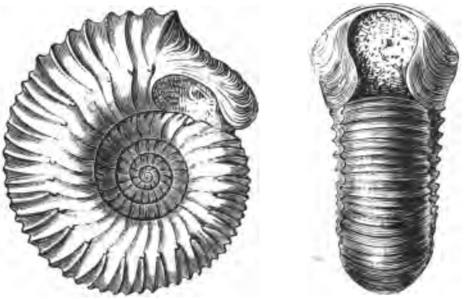

Fig. 108. *Stepheoceras* (*Normannites*) *braikenridgei*, from the Inferior Oolite. × ⅔.

Macrocephalites. Shell without a keel, whorls largely embracing, external margin rounded, umbilicus small. Ribs numerous, dividing near the umbilicus, continued over the external margin, and without tubercles. Aperture without lobes. Sutures deeply divided, with auxiliary lobes. Great Oolite to Kellaways Rock. Ex. *M. macrocephalus*, Cornbrash.

Perisphinctes. Shell discoidal, external margin rounded; umbilicus generally large. Ribs straight, continuous, bifurcating once or more near the external border. Constrictions are often present at intervals on the whorls. Sutures much divided; external and superior-lateral lobes large, inferior-lateral lobe small. Inferior Oolite to Cretaceous. Ex. *P. biplex*, Kimeridgian.

Peltoceras. Umbilicus large; whorls generally quadrilateral, with broad external margin, the inner whorls with numerous continuous ribs, most of which divide near the external margin, across which they extend; the later whorls with two rows of tubercles on the sides, one near the outer, the other near the inner margin. Sutures moderately divided, with large external saddle. Kellaways Rock and Oxfordian. Ex. *P. athleta*, same range.

Parkinsonia (fig. 97 *A*). Shell discoidal, umbilicus large; ribs nearly straight, sharp, simple or bifurcating near the external border, but interrupted at the external margin by a groove. Aperture with processes from the sides. Body-chamber short. Sutures deeply divided; external lobe a little larger than the superior-lateral. Inferior Oolite. Ex. *P. parkinsoni*.

Cosmoceras. Shell flattened; umbilicus large. Ribs numerous, bifurcating at the middle of the sides of the shell, where there is generally a row of tubercles, and ending in a tubercle or spine at the external margin; sometimes with tubercles at the edge of the umbilicus. Body-chamber very short. Aperture with long lateral lobes. Sutures much divided; the external lobe much shorter than the superior-lateral lobe; there are several auxiliary lobes. Inferior Oolite to Lower Cretaceous. Ex. *C. jason*, Oxfordian.

Hoplites. Shell flattened; umbilicus small. Ribs curved, bifurcating, and generally bearing near the umbilicus or at the middle of the sides a row of small tubercles; the external margin is flattened or deeply grooved. Sutures finely divided; many auxiliary lobes. Cretaceous. Ex. *H. splendens*, *H. interruptus*, Gault.

Acanthoceras. Whorls thick; umbilicus large; ribs simple or branching, with rows of tubercles at the sides and margin; external margin broad with a median row of tubercles. Saddles broad. Chalk. Ex. *A. rhotomagense*.

Crioceras. Shell coiled in a plane spiral; the whorls not in contact. Surface ornamented with ribs which in some cases bifurcate and often bear tubercles and spines. Sutures with four lobes. Jurassic to Chalk. Ex. *C. ellipticum*, Chalk.

Ancyloceras. Like *Crioceras*, but the last whorl is produced in a straight line and then bent back in the form of a hook. Cretaceous. Ex. *A. spinigerum*, Gault.

Scaphites. Shell coiled in a plane spiral; the whorls in contact and embracing, except the last, which is detached from the spiral and then recurved in the form of a hook. Body-chamber long. Surface ornamented with bifurcated ribs which often bear tubercles. Sutures generally much divided, with several auxiliary lobes. Upper Cretaceous. Ex. *S. æqualis*, Lower Chalk.

Schlœnbachia. Shell with an umbilicus; external margin broad with a smooth keel; surface with strong ribs, which are slightly curved forwards and often bear tubercles. External and superior-lateral saddles broad; one auxiliary lobe. Cretaceous. Ex. *S. varians*, Lower Chalk.

ORDER II. DIBRANCHIA.

The Dibranchia are represented at the present day by the cuttle-fishes, the squids, the calamaries, octopuses, paper-nautilus, etc.; they are of much less importance geologically than the Nautiloids and Ammonoids, the only really common fossil form being *Belemnites*. Some of the modern cuttle-fishes attain a length of forty feet or more.

The Dibranchia (fig. 93) have a sac-like or elongated body, and possess one pair of gills only; they have also one pair of auricles and one pair of kidneys. The number of arms is limited to eight or ten; and on the inner side—that facing the mouth—they are provided with rows of sucking-discs, which sometimes possess horny hooks. The jaws are not calcified, and are consequently seldom preserved in fossil specimens. An ink-sac is always present, and is occasionally found fossil. The funnel is in the form of a complete tube.

A skeleton is absent in some forms; when present it is (except in *Argonauta*) internal, being enclosed by the mantle; it may be either horny or calcareous. In some cases (*Sepia*) it has the form of a flattened spoon-like body, known as the *cuttle-bone,* which is composed mainly of laminated calcareous material with spaces between the laminæ, and occasionally at the dorsal end there is a trace of a small chambered portion. In the squids the skeleton is lamellar in form and consists of horny material; it is termed the *pen* or *gladius.* The shell in the cuttle-fishes and squids is placed on the antero-dorsal surface of the body in a sac formed by the mantle. In *Spirula* the shell presents some resemblance to that of a Tetrabranch, but is internal, being almost entirely covered by the mantle; it is situated at the dorsal end of the body, and consists of a tube coiled in a plane spiral and divided up into chambers by means of septa, which are traversed by a siphuncle placed near the inner margin; the coils of the shell are not in contact. In *Belemnites* the skeleton consists of a solid portion, the *guard,* and of a chambered part with a siphuncle. The shell in the paper-nautilus (*Argonauta*) is of quite a different nature to that found in other forms; it is external and spiral but not chambered, and is said to be secreted mainly by the basal portions of the two anterior arms, but may be formed, in part, by the mantle; it is found only in the female, serving for the reception of the eggs.

The Dibranchia are divided into two sub-orders:—(1) the Decapoda, (2) the Octopoda.

SUB-ORDER I. DECAPODA.

There are ten arms, eight of equal length and two longer than the others: the suckers are stalked and are provided with a horny ring. The free ends of the two longer arms are swollen and bear suckers there only. An internal shell is always present.

The genera *Spirula* and *Sepia*, already mentioned, belong to this sub-order; the former does not occur fossil and the latter only rarely. Allied to *Sepia* is the genus *Belosepia* found in the Eocene. The most important fossil form is *Belemnites.*

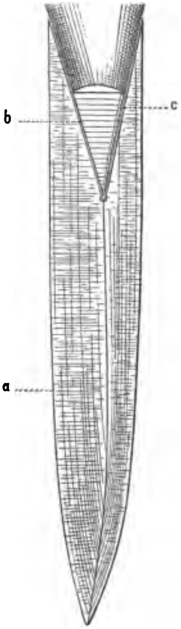

FIG. 109. Longitudinal section of *Belemnites.* *a*, guard; *b*, phragmocone; *c*, siphuncle traversing the chambers of the phragmocone. × ½.

Belemnites (figs. 109, 110, 111). The shell in this genus consists of three parts—the guard (fig. 109, *a*), the phragmocone (*b*), and the pro-ostracum (110, *d*). The guard is solid and is much more commonly preserved than the other parts; it varies considerably in shape and size, being cylindrical, fusiform, conical, etc. The end which was directed away from the mouth is always pointed, and at the other end there is a conical cavity or alveolus. The length of the guard varies from one to fifteen inches.

When sliced transversely or longitudinally it is seen to be formed of a number of layers arranged concentrically around an axial line, which is not quite central but is placed nearer the under surface; these layers are not of uniform thickness along the whole length of the guard, but become thicker towards the pointed end and are thinner towards the broad end. Each layer is formed of minute prisms of calcite, which are placed perpendicular to the axial line, thus producing a radiating fibrous appearance in cross-sections. The surface of the guard is sometimes smooth, or it may be granular, or furnished with ramifying vascular impressions; in some species there is a longitudinal groove on the under surface.

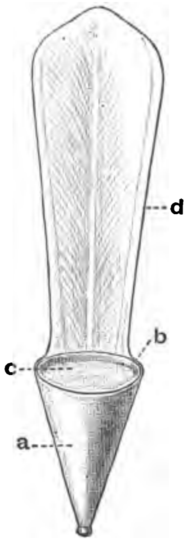

Fig. 110. Phragmocone and pro-ostracum of *Belemnites* from the Lias. Restoration by G. C. Crick. *a*, phragmocone; *b*, front border of phragmocone; *c*, last septum of phragmocone; *d*, pro-ostracum. × $\frac{2}{3}$.

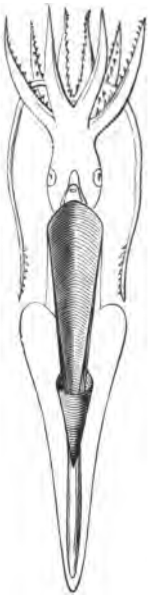

Fig. 111. D'Orbigny's restoration of a Belemnite, showing the probable positions of the guard, the phragmocone, and the pro-ostracum.

The phragmocone (figs. 109 *b*, 110 *a*) is a hollow cone which fits into the alveolus at the broad end of the guard; it is divided up into chambers by septa which are concave in front; a siphuncle (fig. 109, *c*) traverses the chambers at the under margin; at the pointed end of the phragmocone is a small globular protoconch formed of calcareous material. The wall of the phragmocone (sometimes termed the *conotheca*) is very thin, and in well-preserved specimens the upper part is found to be produced in front into a large laminar expansion (fig. 110, *d*); this prolongation is known as the *pro-ostracum*, and corresponds to the 'pen' of the squids. The probable positions of the guard, phragmocone and pro-ostracum in the body of the Belemnite are shown in fig. 111. The suckers on the tentacles were provided with horny hooks, which are sometimes preserved fossil; there was a double row of hooks on each arm, but only six double rows have yet been found in any specimen, so that it seems probable that the Belemnites possessed six arms only. The ink-sac and mandibles have also been found in a few specimens. The 'genus' *Belemnites* is founded mainly on the characters of the guard, and includes an enormous number of species. Probably if the soft parts were known, they would show such differences as to indicate a number of distinct genera. Lower Lias to Upper Cretaceous. Ex. *B. acutus*, Lias; *B. oweni*, Oxford Clay, etc.; *B. hastatus*, Oxford Clay.

Belemnitella. Similar to *Belemnites*. Guard cylindrical, with a slit at the under side of the alveolus. There are well-marked vascular impressions on the under surface of the guard. Chalk. Ex. *B. mucronata*, Upper Chalk.

Actinocamax. Similar to *Belemnites*. Guard cylindrical, with the part around the alveolus fragile and usually not preserved; phragmocone usually separated from the guard by a space. Upper Cretaceous. Ex. *A. quadratus*, Upper Chalk.

Aulacoceras. Similar to *Belemnites*, but guard relatively short, with a groove extending down each side. Phragmocone resembling *Orthoceras*; much longer than the guard, with siphuncle at the margin, and septa rather widely separated; surface of phragmocone with longitudinal lines. Pro-ostracum unknown. Upper Alpine Trias. Ex. *A. reticulatum*.

Belemnoteuthis. Guard reduced in size, forming a thin layer over the phragmocone, with a groove on the upper (dorsal) side starting from the pointed end. Phragmocone with numerous septa, a marginal siphuncle, and septal necks. Pro-ostracum relatively small, seldom preserved. Chiefly Oxfordian. Ex. *B. antiqua*.

SUB-ORDER II. OCTOPODA.

There are eight arms only; the suckers are sessile and possess no horny ring. The shell is rudimentary or absent. *Octopus* and *Argonauta* are well-known examples of this group. The Octopoda, as might be expected from the general absence of a shell, are very poorly represented in the fossil state; the earliest known form is *Palæoctopus* from the Chalk of Lebanon. *Argonauta* has been found in the Pliocene Beds.

Distribution of the Cephalopoda.

Nautiloidea. At the present day the Nautiloidea are represented by four species of *Nautilus* only: these occur in comparatively shallow water in the Indian Ocean, the Persian Gulf, the China Sea, and off New Guinea and Fiji, where they are found creeping along the sea-floor or swimming just above it. The group appears much earlier in the geological series than either the Ammonoidea or the Dibranchia. Two genera (*Orthoceras* and *Cyrtoceras*) are found in the Upper Cambrian (Tremadoc Beds). In the Ordovician the Nautiloidea are very much better represented than in the Cambrian, the chief genera being *Orthoceras*, *Cyrtoceras*, and *Endoceras*. The Order attained its maximum development in the Silurian, where the number of species is very great; in the Devonian and Carboniferous there is a slight decline; in the Permian it is poorly represented. The only genus which extends beyond the limit of the Palæozoic period is *Orthoceras*, which is found in the Trias. *Nautilus* occurs first in the Trias and is especially abundant in the Cretaceous; in the Tertiary it is rare and is associated with the genus *Aturia*.

Ammonoidea. The distribution of the Ammonoidea differs from that of the Nautiloidea in that the former are first found in the Devonian, and are more especially characteristic of the Mesozoic formations. *Clymenia* is limited to the Devonian, and 'goniatites' also occur in the rocks of that system as well as in the Carboniferous—*Glyphioceras* being especially characteristic of the latter. Throughout the Mesozoic rocks the ammonites are extremely abundant, and attain their maximum development in the Lias; in the Cretaceous there is a remarkable development of more or less completely uncoiled Ammonoids, *e.g.*, *Hamites, Macroscaphites* (fig. 105), *Baculites, Crioceras, Ancyloceras,* and *Scaphites.* It is a striking fact that the Ammonoidea disappear suddenly at the end of the Cretaceous period.

Dibranchia. The Dibranchia are more numerous and more varied in existing seas than they were at any former period. Some forms are pelagic, others abyssal, but the larger number are found in littoral regions and are distributed in provinces similar to those of other molluscs (p. 237); typical littoral genera are *Octopus, Sepia,* and *Loligo.* The Dibranchia are unknown in the Palæozoic formations, the earliest examples (*Aulacoceras, Phragmoteuthis*) appearing in the Trias. *Belemnites* is the chief form in the Jurassic and Cretaceous, but does not extend into the Tertiary; it is especially abundant in the clayey beds; *Geoteuthis* occurs in the Lias, and *Belemnoteuthis, Plesioteuthis,* etc. in the Upper Jurassic. *Belemnitella* is limited to the Chalk. Dibranchs are relatively rare in the Eocene.

The principal genera of Cephalopoda which occur in the different formations are:

Cambrian. *Orthoceras* and *Cyrtoceras* appear in the Upper Tremadoc Beds.

Ordovician. *Orthoceras*, *Cyrtoceras*, *Endoceras*.

Silurian. *Orthoceras*, *Cyrtoceras*, *Gomphoceras*, *Trochoceras*, *Ascoceras*.

Devonian. Nautiloidea:—*Orthoceras*, *Cyrtoceras*, *Gyroceras*. Ammonoidea:—*Clymenia*, *Anarcestes*, *Tornoceras*.

Carboniferous. Nautiloidea:—*Orthoceras*, *Cyrtoceras*, *Actinoceras*, *Gyroceras*, *Discites*, *Cœlonautilus*, *Pleuronautilus*, *Temnocheilus*. Ammonoidea:—*Glyphioceras*, *Gastrioceras*, *Prolecanites*.

Permian. *Orthoceras*.

Trias. Nautiloidea:—*Nautilus*, *Orthoceras*. Ammonoidea:—*Pinacoceras*, *Ceratites*, *Trachyceras*, *Ptychites*, *Arcestes*, *Cladiscites*. Dibranchia:—*Aulacoceras*, *Phragmoteuthis*.

Lias. Nautiloidea:—*Nautilus*. Ammonoidea:—*Oxynoticeras*, *Amaltheus*, *Phylloceras*, *Lytoceras*, *Psiloceras*, *Arietites*, *Ægoceras*, *Schlotheimia*, *Harpoceras*, *Cœloceras*, *Dactylioceras*. Dibranchia:—*Belemnites*, *Xiphoteuthis*, *Geoteuthis*.

Oolites. Nautiloidea:—*Nautilus*. Ammonoidea:—*Cardioceras*, *Ludwigia*, *Haploceras*, *Stepheoceras*, *Macrocephalites*, *Perisphinctes*, *Peltoceras*, *Aspidoceras*, *Cosmoceras*, *Parkinsonia*. Dibranchia:—*Belemnites*, *Belemnoteuthis*, *Acanthoteuthis*.

Cretaceous. Nautiloidea:—*Nautilus*. Ammonoidea:—*Macroscaphites*, *Hamites*, *Turrilites*, *Baculites*, *Olcostephanus*, *Desmoceras*, *Pachydiscus*, *Hoplites*, *Douvilleiceras*, *Acanthoceras*, *Crioceras*, *Scaphites*, *Schlœnbachia*. Dibranchia:—*Belemnites*, *Actinocamax*, *Belemnitella*.

Eocene. Nautiloidea:—*Nautilus*, *Aturia*. Dibranchia:—*Belosepia*, *Beloptera*, *Spirulirostra*.

PHYLUM ARTHROPODA.

Classes. *Orders.* *Sub-Orders.*

- 1. Crustacea.
  - 1. Entomostraca.
    - 1. Phyllopoda.
    - 2. Trilobita.
    - 3. Ostracoda.
    - 4. Copepoda.
    - 5. Cirripedia.
  - 2. Malacostraca..
    - 1. Leptostraca.
    - 2. Thoracostraca.
      - 1. Cumacea.
      - 2. Schizopoda.
      - 3. Stomatopoda.
      - 4. Decapoda.
    - 3. Arthrostraca.
      - 1. Amphipoda.
      - 2. Isopoda.
- 2. Prototracheata (not fossil).
- 3. Myriapoda.
- 4. Insecta..............................
  - 1. Aptera.
  - 2. Orthoptera.
  - 3. Neuroptera.
  - 4. Lepidoptera.
  - 5. Coleoptera.
  - 6. Hemiptera.
  - 7. Diptera.
  - 8. Hymenoptera.
- 5. Arachnida ....
  - 1. Xiphosura.
  - 2. Eurypterida.
  - 3. Scorpionida.
  - 4. Pseudoscorpionida.
  - 5. Pedipalpi.
  - 6. Araneida.
  - 7. Phalangida.
  - 8. Acarina.
  - 9. Anthracomarti.

THE Arthropods have a bilaterally symmetrical and segmented body, but not all the segments are alike, and some are usually fused together. Some, or all of the segments, bear a pair of jointed appendages, those near the mouth being modified to serve as organs of mastication and prehension. A chitinous exoskeleton is always present, and is often strengthened by the deposition of carbonate or phosphate of lime. A heart is found in most forms; it is placed dorsally, and is provided with paired slits, termed ostia. The body-cavity contains blood. In some forms respiration takes place by means of the general surface of the body; others are provided with special organs—gills (or branchiæ), tracheæ, pulmonary sacs (or lung-books). The gills are generally thin projections of the skin borne by some of the appendages; the tracheæ are long, branching tubes, filled with air, which penetrate all parts of the body and open to the exterior; the pulmonary sacs or lung-books are chambers containing leaf-like folds of the skin. The nervous system consists of a supra-œsophageal ganglion or brain, connected by a ring round the œsophagus, with a ventral cord, usually provided with ganglia, and placed beneath the intestine. Cilia are absent in all members of the group, with the exception of *Peripatus*. The sexes are separate in almost all forms.

The Arthropoda are divided into the following classes:—(1) Crustacea, (2) Prototracheata, (3) Myriapoda, (4) Insecta, (5) Arachnida. The Prototracheata include one genus only—*Peripatus*, which has not been found fossil.

CLASS I. CRUSTACEA.

The members of this class are mainly aquatic animals, and are abundant as fossils; they breathe generally by means of gills, but in some cases respiration takes place through the general surface of the body. The chitinous exoskeleton is frequently hardened by a calcareous deposit,—hence the name Crustacea. Segmentation is usually well marked, but in the Ostracoda is shown by the appendages only. Three regions may be distinguished in the body:—the head, the thorax, and the abdomen; but in the lower forms the abdomen is often not clearly marked off from the thorax. There are five segments in the head, but these are indicated only by the appendages; the number in the thorax and abdomen is variable in one of the two great divisions, namely, the Entomostraca, but is constant in the other, the Malacostraca. In many forms some or all of the segments of the thorax (and sometimes also the anterior segments of the abdomen) fuse with those of the head to form a *cephalothorax*; this is covered dorsally by a large unsegmented shield or carapace, termed the *cephalothoracic shield.* The head usually bears five pairs of appendages, viz. two pairs of feelers or antennæ, one of mandibles, and two of maxillæ. The thorax is also provided with appendages, and very often the abdomen too. The mandibles and maxillæ, and frequently some of the anterior thoracic appendages, serve as jaws. Each appendage is typically biramous, consisting of a basal part (*protopodite*) bearing two branches—the *endopodite* and the *exopodite.* The mouth is placed on the under surface of the head, and the anus is on the last segment of the abdomen. Eyes are generally present and are placed on the head; in some cases they are simple, in others compound, consisting of a number of lenses. The sexes are separate except in some cirripeds and isopods.

In some Crustacea development is direct, that is to say, the young individual has the same form as the adult; but generally this is not the case, the young undergoing a metamorphosis before reaching the adult stage. The two chief larval forms are known as the *Nauplius* and the *Zoœa*. In the *Nauplius* form the body is unsegmented, and possesses three pairs of appendages representing the two pairs of antennæ and the mandibles. In the *Zoœa* stage some of the thoracic appendages are present also, and the abdomen is segmented but possesses no appendages.

The Crustacea are divided into two large groups, (A) the Entomostraca, (B) the Malacostraca.

A. ENTOMOSTRACA.

The forms included in this group are mostly of small size and of comparatively simple organisation. The number of segments in the body is variable, and also the number and form of the appendages; often the posterior part of the body is without appendages, and the abdomen not clearly separable from the thorax. In the development there is nearly always a *Nauplius* stage. There are five orders:—(1) Phyllopoda, (2) Trilobita, (3) Ostracoda, (4) Copepoda, (5) Cirripedia. The Copepods are not definitely known as fossils.

ORDER I. PHYLLOPODA.

The Phyllopoda include the water-fleas (*Daphnia*, etc.) and other forms. The body is more or less distinctly segmented, and often the greater part, or sometimes the whole, of it is covered by a carapace which may be shield-like, as in *Apus*, or in the form of a bivalved shell, as in *Daphnia*. The number of segments in the abdomen and thorax varies very widely. On the head there are generally two pairs of antennæ, one of mandibles, and one or two of maxillæ. The thorax bears several pairs of swimming-feet, which are leaf-like—hence the name Phyllopoda. The abdomen is indistinctly marked off from the thorax, and may be without appendages; or appendages may be present except on the posterior segments; in *Apus* as many as fifty-two pairs of abdominal legs are found. The last segment of the abdomen often bears two spine-like processes forming a caudal fork. Two large eyes are present, and often also a small unpaired eye.

Estheria (fig. 112). Valves equal, thin, horny; ovate, oblong or quadrilateral, united at the straight dorsal border; the apices of the valves placed anteriorly, or nearly central. Surface generally covered with concentric ridges or striæ. Old Red Sandstone to present day. Lives in fresh or rarely in brackish water. Ex. *E. minuta*, Trias, etc.

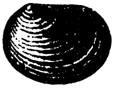

FIG. 112. *Estheria minuta*, from the Trias. ×3.

Distribution of the Phyllopoda.

The Phyllopods live mainly in fresh or brackish water. Only a very few genera are found fossil; *Protocaris*, which resembles *Apus*, occurs in the Lower Cambrian of North America. In the Upper Palæozoic and later deposits a few other genera are present, *Estheria* being common. *Apus* ranges from the *Trias* to the present day.

ORDER II. TRILOBITA.

The Trilobites derive their name from the fact that the body is divided into three parts, by means of two furrows, which extend from the anterior to the posterior extremities; in a few genera, however (*e.g. Homalonotus, Illænus*), this trilobation is only very feebly shown, or is almost absent. In a longitudinal direction three regions can also be distinguished in the body—the head (fig. 113 *A*), the thorax (*B*), and the pygidium (*C*). The segments of the head and of the pygidium are fused together, but those of the thorax remain free.

The dorsal surface of the body is protected by a calcareous shell. The part which covers the head is known as the *head-shield* or *cephalic shield*, and is semicircular or triangular in shape; in it may be distinguished a median and two lateral portions; the former is the more convex and is termed the *glabella* (*a*), the latter are the *cheeks*.

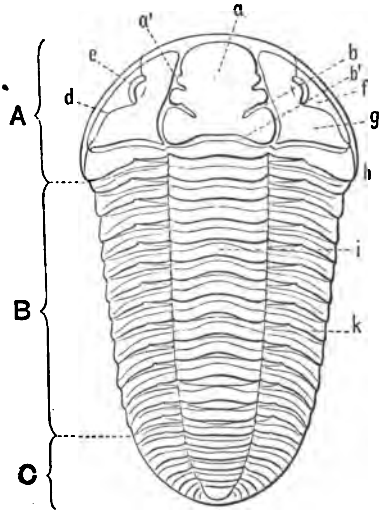

Fig. 113. *Calymene blumenbachi*, from the Wenlock Limestone. *A*, head, *B*, thorax, *C*, pygidium. *a*, glabella; *a'*, axal furrow; *b*, one of the glabella furrows; *b'*, neck furrow; *d*, facial suture; *e*, eye; *f*, free cheek; *g*, fixed cheek; *h*, genal angle; *i*, axis of thorax; *k*, pleura. Natural size.

The glabella is marked off from the cheeks by means of a furrow on each side, known as the *axal furrow* (*a′*). The form of the glabella varies in different genera; in some it extends quite to the anterior margin of the head-shield, in others only a part of the way (fig. 119); sometimes it is wider behind than in front; in other cases it is wider anteriorly, or it may be of uniform width throughout. Generally it is divided at the sides into lobes by means of transverse furrows (*b*),—often three on each side, but sometimes one, two, or four; in some cases the furrows from the two sides meet at the middle of the glabella. On the posterior part of the glabella there is another furrow, which extends quite across it and is continued on to the cheeks; this is known as the *neck-furrow* (*b′*), and the raised part of the glabella behind it is the *neck-ring*. The glabella furrows are probably indications of the original segments which have become fused to form the head.

The cheeks are more or less triangular in shape and less convex than the glabella; they are frequently bordered by a flattened margin which in *Trinucleus* is very broad and highly ornamented. The posterior angles of the cheeks, often spoken of as the genal angles (*h*), may be rounded (*e.g.* *Calymene*), but are often pointed or produced into spines (*e.g.* *Paradoxides*, fig. 120). Each cheek is divided into two portions by a suture (the *facial suture*, *d*); the inner part—that between the facial suture and the glabella—is termed the *fixed cheek* (*g*) and is immovable; the outer part, known as the *free cheek* (*f*), is movable on the fixed cheek. The course of the facial suture varies in different forms: it may commence at or near the genal angle (*h*), or on the posterior border inside the genal angle (fig. 121), or on the external border in front of the genal angle; it bends inwards to the eye and then passes anteriorly, and may be continuous with the suture of the other cheek in front of the glabella, or it may cut the anterior margin of the head-shield, in which case it is often united with the other suture on the inferior surface of the head (*e.g. Calymene*). When the sutures are continuous in front of the glabella it is obvious that the cheeks will also be continuous. Since the position of the facial suture varies in different genera the relative sizes of the fixed and free cheeks will obviously vary too; thus in *Illænus* the free cheek is very narrow, in *Phillipsia* very broad. Most authors state that the facial suture and the free cheek are absent in *Agnostus* and in a few other genera; but according to Beecher the facial suture in such forms is either at the margin or on the ventral surface of the cephalic shield, and the free cheek is then on the ventral surface; this statement, so far as *Agnostus* is concerned, has however been denied by Lindström and Holm.

The eyes (fig. 113, *e*) are placed on the upper surface of the head, one on each free cheek near the facial suture, and generally near the middle of the cheek; they are usually compound, and in most cases consist of a large number of lenses—in *Remopleurides* the number is stated to be 15,000. Usually the entire eye is covered by a continuous cuticle, but in *Phacops* and its sub-genera the eyes are more highly developed, each element of the compound eye possessing an independent cornea. In some forms (*Harpes*) compound eyes do not occur, but simple eyes (one to three in number) are present on the *fixed* cheek. In a few genera

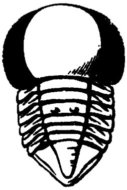

FIG. 114. *Æglina binodosa*, Arenig Beds. Natural size.

(*Agnostus, Ampyx*) eyes are absent; in *Æglina* (fig. 114) they are unusually large, occupying the greater part of the free cheeks. Many of the Cambrian Trilobites which have hitherto been regarded as possessing eyes (*Paradosides, Olenellus, Olenus, Sao*) are now considered by Lindström to have been blind, since the eye-like ridge, which is present, shows no indication of structure and differs in development from that of the eyes, which always appear in close connexion with the facial suture.

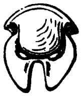

FIG. 115. Hypostome of *Asaphus tyrannus*, from the Llandeilo Beds. Reduced.

The head-shield is continued on the under surface of the head, forming a marginal rim (fig. 116, *a*); attached to this in the median line is a plate, usually oval in shape, situated just in front of the mouth and known as the *hypostome* or *labrum* (figs. 116 *b*, 115). Just behind the mouth is a small plate, the *metastoma* (fig. 117 *A*, *m*); up to the present time this has been observed in the genus *Triarthrus* only.

In many Trilobites a small slightly-raised tubercle, or a small depressed area, is found on each side of the hypostome just behind the middle of its outer surface; these *maculæ* are sometimes entirely smooth, but in other cases a part, or the whole of the surface, shows a structure similar to that of the compound eyes on the dorsal surface of the head. Lindström regards the maculæ as visual organs. They are unknown in any other Crustacea, and at present their nature cannot be regarded as definitely determined.

The thorax (fig. 113 *B*) is formed of a series of segments, which vary in number from two to twenty-six; these are movable upon one another, in some cases sufficiently to enable the animal to roll itself up like a woodlouse. Each segment is divided into a central and two lateral parts by means of two furrows. The central part is more convex than the lateral, and forms the axis (*i*), the lateral parts being known as the pleuræ (*k*). The anterior part of the axis of each segment is not visible when the animal is unrolled, since it is bent down and is overlapped by the preceding segment, for which it forms an articular surface. The pleuræ in some genera possess a longitudinal ridge, in others a groove, or both ridges and grooves may occur; a few forms have plane pleuræ. Each pleura, at some distance from the axis, is curved downwards and usually also backwards; the point where this curvature occurs is known as the fulcrum; often the outer part of each pleura overlaps the anterior part of the succeeding one, and the fulcrum may be rounded so as to form an articulating facet. The terminations of the pleuræ are in some cases rounded (fig. 113), in others produced into spines (fig. 120).

The pygidium (fig. 113 *C*) is usually triangular or semicircular in shape, and is formed of a variable number of segments, which differ from those of the thorax in being fused together and immovable; the segmentation is shown by grooves only. The pygidium, like the thorax, possesses a central part or axis, and lateral portions; the axis may reach quite to the posterior extremity or only part of the way, and it tapers more rapidly than the axis of the thorax; in *Bronteus* it is very short. The margin of the pygidium may be even or entire, or it may be provided with a posterior spine or with lateral spines.

For a long time the appendages of the trilobites were unknown, and even now only a few specimens showing the ventral surface have been found. One of these is an example of *Asaphus megistos* (fig. 116) from the Ordovician Beds of Ohio. In this, each segment of the thorax and pygidium

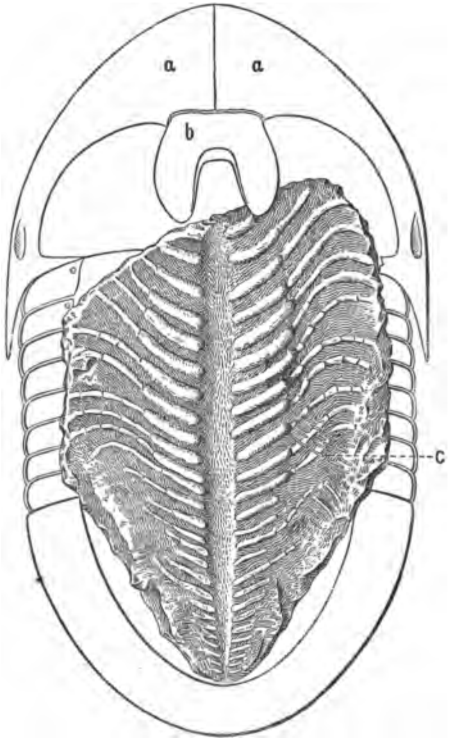

Fig. 116. Under surface of *Asaphus megistos*, from the Ordovician rocks of Ohio, showing a pair of appendages attached to each segment. The shaded part represents the actual specimen. *a*, infolded margin of the head-shield; *b*, hypostome; *c*, branchial filaments? (After Walcott.)

was found to bear a pair of jointed appendages. Walcott has obtained further information on this subject by cutting thin sections of rolled-up specimens of *Calymene* and

Cheirurus. By this method he ascertained that on the ventral surface of the body there was a thin, uncalcified membrane, strengthened by transverse arches to which the appendages of the thorax and pygidium were attached; each of these appendages consisted of six or seven joints, and at the base a spiral structure (regarded as a gill) was attached. The head also carried pairs of jointed appendages.

Specimens showing the ventral surface much more perfectly have recently been obtained from the Utica Slate near Rome (New York), and have been fully described by Beecher. The most important of these belong to the genus *Triarthrus* (fig. 117); they are not curled up, and exhibit very clearly the form of the limbs. Each segment of the body bears one pair of appendages, which, with the exception of the first, are biramous, consisting of a basal joint bearing two branches. On the head there are five pairs of appendages; the *first* are the long antennæ which have a large basal joint and are attached on each side of the hypostome (*h*). These antennæ are considered by Beecher to represent the antennules (or anterior antennæ) of other Crustacea. The remaining four pairs of appendages of the head are biramous and all have nearly the same form but increase in size backwards: the *second* pair are considered to represent the antennæ, the *third* the mandibles, and the *fourth* and *fifth* pairs the maxillæ of other Crustacea. The maxillæ consist of a large basal joint (the *coxopodite*) which bears the *endopodite* and the slender *exopodite*; the latter carries a bunch of hairs or *setæ*.

The anterior appendages of the thorax are long and consist of a coxopodite (fig. 117 *C, D*) which bears the six-jointed endopodite (*a*) and the exopodite (*b*)—the first joint of the latter is large, the others small and numerous. The exopodite bears setæ and probably served as a swimming organ, whereas the endopodite was adapted for crawling. The posterior thoracic limbs do not differ essentially from the anterior one just described, but they diminish in size posteriorly and were better adapted for swimming. In each segment the ventral membrane between the bases of the limits is strengthened by a median

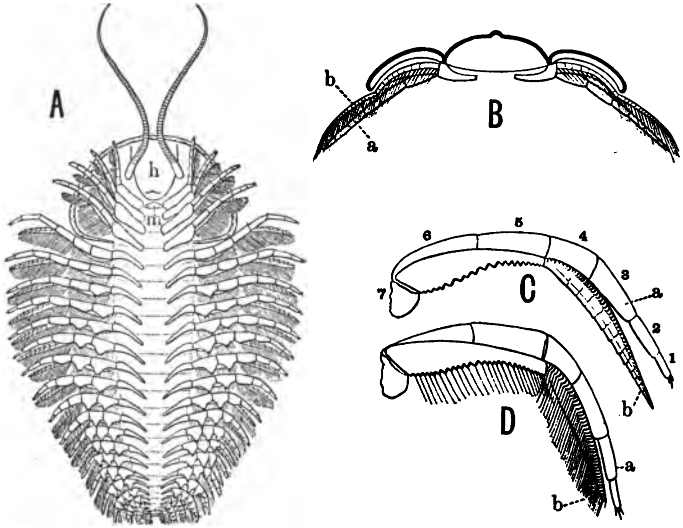

Fig. 117. *Triarthrus becki*, from the Utica Slate (Ordovician) near Rome, New York. (After Beecher.)

A, view of the ventral surface showing appendages, etc. *h*, hypostome; *m*, metastoma. × 1⅔.

B, diagrammatic section through the second thoracic segment. *a*, endopodite; *b*, exopodite.

C, *D*, dorsal view of the right legs of the second and third thoracic segments (setæ omitted from *C*). *a*, endopodite; *b*, exopodite. × 12.

longitudinal ridge and one or two oblique ridges on each side.

The appendages of the pygidium are leaf-like and resemble closely the limbs of Phyllopods, particularly *Apus.* The leaf-like character is due to the flattening and expansion of the first segments of the endopodite which bear setæ; the exopodite is slender. The anal opening is quite at the end of the pygidium.

In some fine-grained rocks, especially in the Lower Palæozoic of Bohemia, the larval forms of Trilobites are found well preserved, so that it is possible to trace out the changes which occurred in the development of the individual. In the earliest stage (fig. 118 *A*), called the *protaspis* by Beecher, the body is discoid or ovate in form, and con-

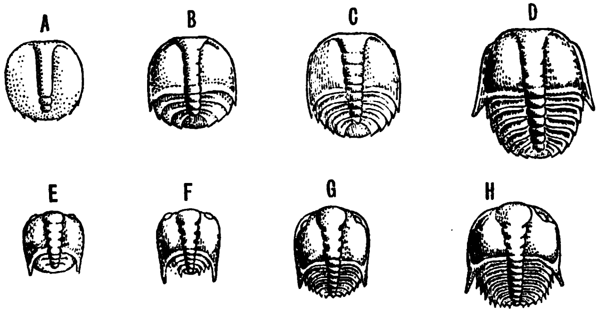

FIG. 118. Development of Trilobites. (After Barrande.)

A—D. Sao hirsuta, Cambrian, Bohemia. *A*, earliest stage, x 12. *B*, later stage with three segments behind the head, x 12. *C*, with distinct glabella furrows, and four segments behind the head, x 12. *D*, with six segments behind the head, x 10.

E—H. Phacops (*Odontochile*) *socialis*, Ordovician, Bohemia. x about 8. *E*, earliest-known stage, with eyes at the margin, and three segments behind the head. *F*, later stage with more distinct furrows on the glabella, and four segments behind the head. *G*, with eyes moved inward, and narrow free cheek; six segments behind the head. *H*, free cheeks relatively larger and eight segments behind the head.

sists chiefly of the cephalic region in which the glabella is distinct and is divided by furrows; eyes, when present, are at or near the outer front margins of the shield (fig. 118 *E*), and the free cheek, if visible on the dorsal surface, is narrow (*G*). The glabella usually reaches the front margin of the head. In later stages the pygidium becomes distinct and increases in size; and the thoracic segments are gradually introduced between the head and the pygidium (*C*, *D*). At the same time the eyes move backwards and inwards until they attain their adult position, and the free cheeks increase in size (*H*). The glabella becomes rounded in front and usually relatively shorter. Since in the earliest stages of all Trilobites the free cheeks are either absent from the dorsal surface or are narrow, Beecher regards the Trilobites which retain this character in the adult state as more primitive than those in which the free cheek becomes relatively large and the fixed cheek narrow. Beecher considers that the protaspis of Trilobites corresponds to one of the Nauplius stages (the metanauplius) of recent Crustacea.

The possession of antennæ and the biramous character of the other appendages show that the Trilobites belong to the Crustacea. The great variability in the number of segments connects them with the Entomostraca; the leaf-like character of the appendages on the posterior part of the body seems to show that they are related to the Phyllopoda, and especially to *Apus*, with which genus they also agree in possessing a similar labrum or hypostome. On the other hand the anterior thoracic limbs resemble those of Schizopods. But the Trilobites differ from the Phyllopods in the trilobation of the body, in the posterior segments being fused together, in the appendages of the pygidium being similar to those of the thorax, and in the absence of a caudal fork. The Trilobites, however, are more primitive than any other Crustacea, since all the appendages, except the first pair, are very similar in structure and show but little modification in different regions of the body. They differ also from most other Crustacea in having one pair of antennæ only. For these reasons some authors regard the Trilobites as a primitive group of the Crustacea independent of both Entomostraca and Malacostraca.

The Trilobites show some resemblance to the Palæozoic Xiphosura (p. 317), since some of the latter possess what appear to be facial sutures, and have the segments behind the cephalic region free; but they differ entirely from the Xiphosura in the character and arrangement of the appendages, in the structure of the eyes, in the absence of a genital operculum, etc.

Agnostus. Body small, head-shield and pygidium similar in form and size; eyes and facial suture absent (suture ventral or marginal according to Beecher); glabella does not reach the anterior border of the head. Thorax formed of two segments, axis wide, pleuræ grooved. *Olenellus* Beds to Bala Beds. Ex. *A. pisiformis*, Lingula Flags.

Microdiscus. Similar to *Agnostus* but with four segments in the thorax, and segmentation of axis of pygidium well marked. *Olenellus* Beds to Lingula Flags. Ex. *M. punctatus*, Lingula Flags.

Trinucleus. Head-shield large, with long genal spines, and a broad punctate border; glabella inflated, pyriform, furrows absent or indistinct. Eyes generally absent. Facial suture, when present, at or near the margin. Thorax formed of six segments, pleuræ grooved, straight, but slightly curved near their extremities. Pygidium short, triangular, margin entire. Arenig to Bala Beds. Ex. *T. concentricus*, Bala Beds.

Ampyx. Similar to *Trinucleus*, but with a triangular head-shield which is without a punctate border, and with a long straight spine given off from the front of the glabella; also with discontinuous facial sutures. Free cheeks very narrow. Tremadoc to Wenlock Beds (chiefly Ordovician, only one species in the Silurian). Ex. *A. nudus*, Llandeilo Beds.

Harpes. Resembling *Trinucleus*, but punctate border of head-shield broader and extended posteriorly instead of bearing narrow genal spines. Glabella short, not expanded in front. Simple eyes joined to the front part of glabella by a ridge. Thorax with twenty-five to twenty-nine segments. Ordovician to Devonian. Ex. *H. ungula*, Ordovician.

Olenus (fig. 119). Body oval; head-shield larger than the pygidium, with a narrow border, and with genal spines; glabella not reaching the anterior border, and not expanding in front, usually with three pairs of furrows; facial sutures extend from the posterior margin (near the genal angle) to the front border; 'eyes' (see p. 277) well developed, placed forward and united to the front of the glabella by a straight ridge. Thorax of from twelve to fifteen (typically fourteen) segments; axis narrow, pleuræ with short points. Pygidium small, with three or four segments indicated on the axis, and with entire border. Lingula Flags to Tremadoc Beds. Ex. *O. gibbosus*, *O. cataractes*, Lingula Flags. *Parabolina*, *Peltura*, *Parabolinella*, *Eurycare*, and *Sphærophthalmus* are related to *Olenus* and usually regarded as sub-genera of it.

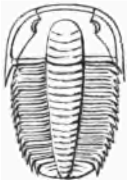

FIG. 119. *Olenus cataractes*, from the Lingula Flags. Natural size.

Paradoxides (fig. 120). Body large, elongated, narrowed posteriorly. Head-shield broad, semicircular, with a border, and long genal spines; glabella broad in front, with two to four furrows on each side. Facial sutures extend from the posterior to the anterior border. 'Eyes' (see p. 277) large and arched. Thorax long, formed of sixteen to twenty segments; pleuræ grooved and produced into long backwardly-directed spines. Pygidium very small, plate-like, axis of two to eight segments. Middle Cambrian. Ex. *P. davidis*, Menevian; *P. bohemicus*, Cambrian.

Olenellus. Similar to *Paradoxides*; but the glabella is of nearly the same width throughout, the facial sutures are invisible, the 'eyes' (see p. 277) are large and join the glabella; there are from thirteen to eighteen segments in the thorax. Some forms have spines on the axis of one or more segments of the thorax and pygidium. In some species there are no lateral lobes on the pygidium. Lower Cambrian. This genus is divided into four sub-genera:—(1) *Olenellus* (restricted); pygidium spine-like, without lateral lobes. Ex. *O. thompsoni.* (2) *Mesonacis*; pygidium large, with lateral lobes, spines on some segments of the axis of thorax or pygidium. Ex. *M. vermontana.* (3) *Holmia*; with a row of spines down the axis of the body—the neck-spine often long. Pygidium small, plate-like. Ex. *H. callavei.* (4) *Olenelloides*, Ex. *O. armatus.* Lower Cambrian.

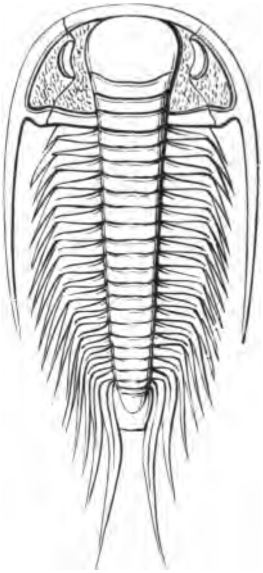

FIG. 120. *Paradoxides davidis*, from the Menevian Beds. × ½.

Conocoryphe (= *Conocephalites*). Head-shield semicircular, with genal spines (not always preserved); axal furrows deep, glabella narrow in front and with three or four backwardly-directed furrows and well-marked neck-furrow; free cheeks narrow. Facial sutures not continuous in front and ending just within the genal angles. Hypostome convex, formed of a central oval portion surrounded by a narrow border. Thorax with fourteen or fifteen segments; pleuræ grooved. Pygidium small, margin entire, axis with from two to eight segments. *Olenellus* Beds to Tremadoc Beds. Ex. *C. lyelli*, Solva Beds; *C. sulzeri*, Cambrian.

Angelina. Body oval. Head-shield with long genal spines, glabella parabolic, without furrows; eyes small, near the middle of the cheeks. Thorax with fourteen or fifteen segments, pleuræ faceted. Pygidium short, margin provided with two teeth, axis of four or five segments. Tremadoc Beds. Ex. *A. sedgwicki.*

Calymene (fig. 113). Head-shield semicircular, genal angles rounded, occasionally pointed; glabella greatly inflated, broadest behind, with three pairs of lateral furrows forming three globular lobes on each side. Eyes small, prominent. Facial sutures extending from the genal angles to the anterior border, where they are connected by a suture below the margin. Thorax formed of thirteen segments, axis prominent, pleuræ grooved and faceted. Pygidium with six to eleven segments, margin entire. Arenig to Upper Ludlow. Ex. *C. blumenbachi,* Wenlock Limestone etc.

Homalonotus. Body large, elongated, with indistinct trilobation. Head-shield broad, genal angles rounded, furrows on the glabella indistinct or absent. Eyes small. Facial suture passing from the genal angles to the front margin, and often continuous in front. Thorax with thirteen segments; axis wide, not well marked. Pygidium triangular, axis with ten to fourteen segments. Arenig to Devonian. Ex. *H. delphinocephalus,* Wenlock Beds; *H. bisulcatus,* Ordovician.

Ogygia. Body large, nearly flat. Head-shield large, semicircular; glabella distinct, wider in front, with four or five lateral furrows. Eyes large. Facial suture starting from the posterior border, sometimes cutting the front margin, but generally continuous. Free cheeks large. Hypostome not notched. Thorax consisting of eight segments, axis narrow, distinct; pleuræ grooved, usually with pointed ends. Pygidium large, semicircular, margin entire, axis of numerous segments. Tremadoc to Llandeilo Beds. Ex. *O. buchi,* Llandeilo Beds.

Asaphus (figs. 115, 121). Body oval, surface smooth or with striæ. Head-shield semicircular with a flattened border, genal angles rounded or spinose; glabella wide in front and usually without lateral furrows. Eyes large. Facial sutures start from the posterior border and are sometimes continuous in front of the glabella, but sometimes cut the anterior margin. Free cheeks large. Hypostome notched posteriorly. Thorax formed of eight segments, pleuræ obliquely grooved, with rounded extremities. Pygidium of about the same size as the head, rounded, formed of numerous segments which are usually visible on the axis only; margin entire. Tremadoc to Bala Beds. Ex. *A. tyrannus*, Llandeilo.

Illænus. Body oval, convex. Head-shield large, semicircular; glabella indistinctly limited, without furrows externally, but within the test there are four pairs. Eyes remote from one another. Facial sutures commence on the posterior border, cut the anterior border in front of eye, and unite on the inferior surface. Free cheeks small. Thorax with usually ten segments, axis usually not well marked, pleuræ not grooved or ridged. Pygidium large, semicircular, axis rudimentary, segments not visible externally. Arenig to Wenlock. Ex. *I. davisi*, *I. bowmanni*, Bala Beds.

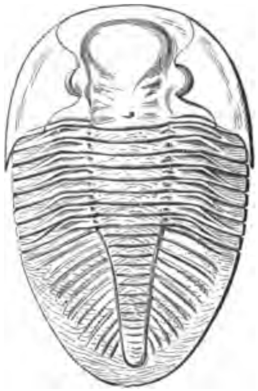

FIG. 121. *Asaphus tyrannus*, from the Llandeilo Beds. × ⅙.

Æglina (fig. 114). Head-shield large; glabella large, convex, projecting beyond the margin in front. Cheeks narrow; eyes very large, occupying nearly all the free cheeks. Facial sutures discontinuous, nearly parallel with the axis of the body. Thorax with five or six segments, axis broad, pleuræ grooved. Pygidium rounded, axis short. Arenig to Bala Beds. Ex. *Æ. binodosa*, Llandeilo Beds.

Bronteus. Head-shield large, semicircular, genal angles pointed. Glabella expanding rapidly in front, with three lateral furrows in some species, none in others. Facial sutures start from the posterior border and are discontinuous in front. Free cheeks large; eyes crescentic, placed near the posterior border. Thorax with ten segments, pleuræ ridged. Pygidium very large, fan-shaped, axis very short, lateral lobes large with radiating grooves. Bala Beds to Devonian. Ex. *B. flabellifer*, Devonian.

Phacops. Head-shield nearly semicircular, glabella prominent, broadest in front, with three or four furrows, which are sometimes indistinct; facial sutures commencing on the lateral borders of the cheeks in front of the genal angle, and continuous in front of the glabella. Eyes generally large, granulated, formed of large and distinct facets. Thorax with eleven segments, pleuræ grooved. Pygidium variable. Ordovician to Devonian.

The species of *Phacops* are divided into a number of groups which should be regarded as sub-genera, or perhaps genera; some of these are:—*Phacops* (restricted): glabella inflated and expanded in front, with the two anterior furrows obscure. Eyes large. No genal spines. Ex. *P. stokesi*, Silurian. *Trimerocephalus*: glabella furrows obscure or absent. Eyes small. No genal spines. Ex. *T. lævis*, Devonian. *Acaste*: glabella not much expanded in front, all the furrows distinct. Ex. *A. downingiæ*, Silurian. *Chasmops*: glabella greatly expanded in front, two anterior furrows large, two posterior very small. Genal spines. Ex. *C. conophthalmus*, Bala Beds. *Odontochile* (=*Dalmanites*): glabella not much expanded, all the furrows distinct. Genal spines long. Pleuræ often produced into spines. Ex. *O. caudatus*, Silurian.

Cheirurus. Head-shield semicircular, genal angles pointed or with spines; glabella convex, oblong or ovoid, with three pairs of furrows which are sometimes continuous across, the last pair uniting with the neck-furrow. Facial sutures continuous in front and ending on the external margins. Free cheeks small; eyes prominent. Thorax with usually eleven segments, pleuræ grooved, and produced into spines. Pygidium small, with four segments, lateral lobes with backwardly-directed spines. Tremadoc to Devonian. Ex. *C. articulatus*, Devonian; *C. bimucronatus*, Bala to Ludlow Beds; *C. juvenis*, Bala Beds.

Deiphon. Glabella globular without furrows. Fixed cheeks forming two long curved spines. Thorax with nine segments; pleuræ in the form of free spines. Pygidium short, prolonged into two spines on each side. Wenlock and Llandovery. Ex. *D. forbesi.*

Encrinurus. Head-shield covered with tubercles; glabella pyriform, its furrows indistinct or absent; eyes small, placed on short peduncles. Facial sutures not continuous, ending just in front of the genal angles. Free cheeks narrow. Thorax with eleven segments, pleuræ ridged. Pygidium narrow, triangular, with many segments in the axis, pleuræ bent backwards. Bala to Upper Ludlow. Ex. *E. punctatus*, Wenlock Limestone.

Lichas. Test covered with tubercles. Head-shield convex, relatively small, with genal spines. Glabella broad, with a central raised part, furrows directed backwards. Facial sutures pass from the posterior border to the anterior. Cheeks and eyes small. Thorax with nine or ten segments; pleuræ grooved, ending in rather long spines. Pygidium large, showing two or three segments, lateral parts produced into spines. Llandeilo to Wenlock. Ex. *L. anglicus*, Wenlock.

Acidapsis (fig. 122). Head-shield broad, usually with spines at the margin, trilobation not well marked, genal angles spined; glabella with a pair of longitudinal furrows parallel to the axal furrows, with two or three lateral furrows. Facial sutures start from the posterior margin just within the genal angle and cut the front margin. Free cheeks large. Eyes connected with the glabella by a ridge. Thorax with nine or ten segments, pleuræ with ridges produced into long spines. Pygidium small, with long spines. Llandeilo Beds to Devonian. Ex. *A. barrandei*, *A. brighti*, Wenlock.

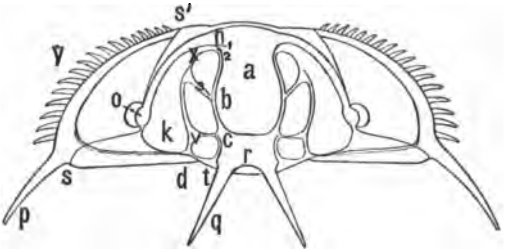

FIG. 122. *Acidaspis prevosti*, from the Silurian Rocks. Outline of the head-shield. (After Barrande.) 1, 2, 3, first, second, and third glabella furrows (the first usually indistinct); *a*, central part of the glabella; *c—b—n*, inner furrow of glabella; *c—v*, neck-furrow; *d—v—x*, axal furrow; *k—x*, fixed cheek; *o*, eye; *o—n*, ridge extending from eye to glabella; *p*, genal spines; *q*, spines from neck-ring; *r*, neck-ring; *s—s'*, facial suture; *y*, spines. Enlarged.

Phillipsia. Body oval; glabella with nearly parallel sides, with two or three short lateral furrows, the posterior one being directed backwards and united to the deep neck-furrow, thus cutting off a basal lobe. Facial sutures cut the posterior border obliquely and the anterior border in front of the eye. Free cheeks large; eyes large, reniform. Thorax with nine segments, pleuræ grooved. Pygidium semicircular, with twelve to eighteen segments, margin entire. Devonian to Permian. Ex. *P. derbiensis*, Carboniferous.

Proetus. Closely allied to *Phillipsia* but with fewer segments in the pygidium. Ordovician to Carboniferous, chiefly Devonian. Ex. *P. fletcheri*, Wenlock.

Griffithides. Body oval; glabella pyriform, without lateral furrows, with inflated basal lobes; eyes small. Thorax with nine segments. Pygidium rounded, formed of about thirteen segments. Carboniferous Limestone. Ex. *G. seminiferus.*

Distribution of the Trilobita.

The Trilobites form one of the most important and striking features in the Palæozoic faunas; they occur first in the Lower Cambrian Beds, and reach their maximum in the Ordovician; they are still abundant in the Silurian, but become less important in the Devonian, and in the Carboniferous are represented by four genera only. In Europe they do not extend beyond the Carboniferous Limestone, but in North America one species of *Phillipsia* has been found in the Permian.

Already in the Cambrian period the Trilobites were represented by a great variety of forms, showing that even then the Order must have been of considerable antiquity, but at present no traces of the ancestors of the Cambrian forms have been found. It is in the Cambrian System that we meet with the largest, as well as the smallest Trilobite known—*Paradoxides* and *Agnostus.* As a whole, it may be said that the Trilobites of the earlier formations are characterised by the possession of a large number of segments in the thorax and by a small pygidium (fig. 120); whereas in the Tremadoc, and particularly in the Ordovician Rocks, they possess large pygidia and have fewer segments in the thorax (fig. 121).

Many of the Trilobites seem to have had a wide geographical distribution; for example, most of the genera which have been recognised in Australia occur also in Europe. Some, however, apparently had a more limited range; thus, for instance, *Sao*, *Arethusina*, and *Ellipsocephalus*, are very common in Bohemia, but the first two have not been found in the British Isles, and the last has been recorded only once.

The most important genera found in the different systems are mentioned below; those marked with an asterisk* occur only in one system.

Cambrian. *Agnostus*, *Microdiscus**, *Paradoxides**, *Olenellus**, *Olenus**; *Sao**, *Ellipsocephalus**, *Concoryphe**, *Niobe*, *Angelina**.

Ordovician. *Agnostus*, *Ogygia*, *Ampyx*, *Trinucleus*, *Illænus*, *Asaphus*, *Æglina**, *Calymene*. *Ogygia*, *Asaphus*, *Trinucleus* and *Ampyx* are abundant, the last two being almost confined to this system.

Silurian. *Phacops*, *Homalonotus*, *Calymene*, *Encrinurus*, *Acidaspis*, *Cheirurus*, *Proetus*, *Illænus*, *Lichas*. *Phacops* and *Acidaspis* are particularly abundant.

Devonian. *Phacops*, *Homalonotus*, *Cheirurus*, *Proetus*, *Bronteus*.

Carboniferous. *Phillipsia*, *Griffithides**, *Brachymetopus**.

ORDER III. OSTRACODA.

The Ostracods (fig. 123) are indistinctly segmented and generally minute. The body is usually compressed laterally and completely enclosed in a bivalved shell or carapace, which may be horny or calcareous. One valve is placed on each side of the animal, and the two valves are joined together dorsally by an elastic ligament which serves to open the shell; an adductor muscle passes from the interior of one valve to the other and by its contraction the shell is closed. There are seven pairs of appendages, which can be protruded when the shell is opened. In some of the marine forms the shell is notched anteriorly so as to allow the antennæ to pass through when the shell is closed. The head carries two pairs of antennæ, one of mandibles, and two of maxillæ. The thorax has only two pairs of appendages, which are not leaf-like. The abdomen is rudimentary and is without appendages; it terminates either in a fork or in a spiny plate. Respiration takes place by means of the general surface of the body. The carapace is in almost all cases the only part which occurs fossil; its surface may be smooth or variously ornamented.

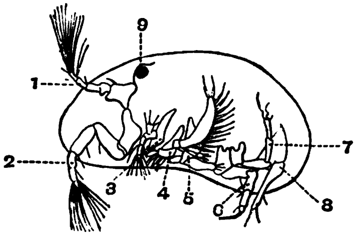

FIG. 123. Lateral view of *Cypris candida*. (After Zenker.) 1, antennules; 2, antennæ; 3, mandibles; 4, first maxillæ; 5, second maxillæ; 6, 7, first and second pairs of legs; 8, tail; 9, eye. Enlarged.

Leperditia. Carapace thick, smooth, convex, elongated, a little higher posteriorly. The right valve larger than the left. Hinge-line straight. There is a small tubercle (eye-spot) placed anteriorly near the hinge; and posterior to it is a slightly elevated circular area. Cambrian to Carboniferous. Ex. *L. hisingeri*, Silurian; *L. okeni*, Carboniferous.

Primitia. Carapace generally equivalve, convex, oblong or ovate. Hinge-line straight. Each valve has a transverse groove which starts from the hinge-line. Cambrian to Carboniferous. Ex. *P. strangulata*, Bala Beds.

Beyrichia (fig. 124). Carapace elongated, inflated, posterior border a little higher than the anterior; dorsal border straight, ventral border semicircular. On the surface there are two or three large furrows which pass from the dorsal towards the ventral edge, the parts between being convex and often tuberculate. Cambrian to Carboniferous. Ex. *B. complicata*, Llandeilo and Bala.

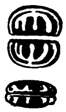

FIG. 124. *Beyrichia complicata*, Bala Beds. The lower figure shows the dorsal aspect of the united valves. × 2.

Entomis. Carapace equivalve, almond-shaped, with a deep transverse furrow which passes from the dorsal border (a little in front of the middle) towards the ventral border. Surface generally striated. Anterior margin notched for the passage of the antennæ. Ordovician to Carboniferous. Ex. *E. tuberosa*, Silurian.

Cythere. Shell oblong-ovate or subquadrate, highest in front; smooth or ornamented with pits, spines or ridges. Hinge with teeth anteriorly and posteriorly. Ordovician to present day (chiefly Cretaceous and later). Ex. *C. striato-punctata*, Eocene; *C. punctata*, Pliocene.

Cypris (fig. 123). Carapace thin, smooth or punctate, kidney-shaped or oval; ventral edge often concave. Left valve the larger. Purbeck Beds to present day. Fresh water. Ex. *C. faba*, Miocene; *C. gibba*, Oligocene to present day.

Cypridea. Valves ovate-oblong, convex in the middle, broad at the anterior third, narrower behind; with a notch at the anterior ventral angle behind a beak-like process. Surface smooth, punctate, or tuberculate. Hinge-margin straight along the middle third of the dorsal edge. Left valve the larger. Purbeck, Wealden, and Hamstead Beds. Fresh water. Ex. *C. valdensis*, Wealden Beds, etc.

Distribution of the Ostracoda.

The Ostracods have a very wide distribution at the present day; they are mainly marine, and often occur in shoals. They are most abundant in shallow water, only fifty-two species being found beyond the 500 fathom line. The fossil forms are very numerous, the earliest occurring in the Cambrian. *Leperditia, Primitia,* and *Beyrichia* are abundant in the Lower Palæozoic; *Entomis* in the Devonian; and *Cypridina* and *Bairdia* in the Carboniferous. *Cypridea* is common in the Purbeck and Wealden Beds; and *Cythere* in the Tertiary formations.

ORDER V. CIRRIPEDIA.

The Cirripedes include the barnacles, acorn-shells, etc., —forms which differ considerably in appearance from the other crustaceans and were for a long time regarded as molluscs. The body is completely enclosed in a fold of the skin, which commonly secretes a calcareous shell. The animal, in the adult state, is fixed to a foreign object by the anterior end of the head, either directly or by means of a stalk or peduncle. The segmentation of the body is indistinct. The head is not well marked off from the thorax; it bears one or two pairs of antennæ, one pair of mandibles, and two pairs of maxillæ. The thorax has usually six pairs of biramous feathery limbs. The abdomen is rudimentary

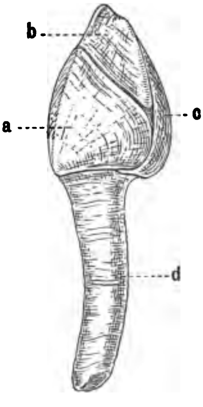

FIG. 125. *Lepas australis*, Recent. *a*, scutum, *b*, tergum; *c*, carina; *d*, peduncle. Natural size. (After Darwin.)

and without appendages. Heart and vascular system are absent; nearly all forms are hermaphrodite. The shell consists of several pieces; in *Lepas* (which possesses a stalk) there are five, two are placed on each side of the body, those near the stalk being termed the *scuta* (fig. 125, *a*), those at the upper end the *terga* (*b*), and there is also one unpaired part placed dorsally, the *carina* (*c*). *Balanus* has no stalk; its shell consists of a tube formed of six pieces, within which the scuta and terga are placed.

Distribution of the Cirripedia.

The Cirripedes are all marine, and the greater number are found in shallow water, particularly near the coasts, *Balanus* being especially characteristic of littoral regions. At depths greater than 1000 fathoms, only two genera, *Scalpellum* and *Verrucosa,* have been found, and these are not confined to deep water.

Cirripedes are rare in the Palæozoic and early Mesozoic formations, but become moderately common in the Chalk, and are abundant in some of the later Tertiary deposits. A few examples have been found in the Cambrian of North America. In the Ordovician the genera *Pollicipes, Scalpellum,* and *Turrilepas* (= *Plumulites*) occur: the first two are represented in the Silurian and various later formations (especially the Chalk); the last ranges on to the Devonian. *Balanus* appears in the Eocene, and *Lepas* in the Pliocene.

B. MALACOSTRACA.

The Malacostraca are usually larger and are more highly organised than the Entomostraca. With the exception of the Leptostraca, the number of segments is constant throughout the group, there being five in the head (or six if the eyes be regarded as appendages), eight in the thorax, and six in the abdomen; each segment bears one pair of appendages. The abdomen is clearly marked off from the thorax. In some cases the development is direct, in a few the Nauplius stage occurs, but more commonly the Zoæa larva is found.

There are three Orders:—(1) Leptostraca, (2) Thoracostraca, (3) Arthrostraca.

ORDER I. LEPTOSTRACA (PHYLLOCARIDA).

The Leptostraca possess characters which connect them with both the Phyllopoda and the Malacostraca. Only three genera are now living, of which the commonest is *Nebalia.* A large bivalved carapace (fig. 126, *m*) covers the head, the thorax, and some of the abdominal segments, but is united to the head only; the two valves are connected by an adductor muscle (*p*) just as is the case in the Ostracods and many Phyllopods. In front of the carapace is a movable plate or *rostrum* (*a*). There are twenty-one segments in the body—five in the head, eight in the thorax (*r*—*t*), eight in the abdomen, the last segment carrying two pointed processes—the caudal fork. There are nineteen pairs of appendages, as in the Malacostraca: the head bears two pairs of antennæ (*c*, *d*), one pair of mandibles (*n*), two of maxillæ (*q*, *o*); on the thorax there are eight pairs of leaf-like limbs (*f*) similar to those of the Phyllopods; the abdomen has six pairs of appendages, the first four being large biramous legs (*g*), the last two small (*h*, *k*). The two posterior segments are without appendages. The eyes are compound and stalked. The mandible bears a long, three-jointed feeler or palp (*e*).

The Leptostraca agree with the Malacostraca in having the abdomen clearly marked off from the thorax;

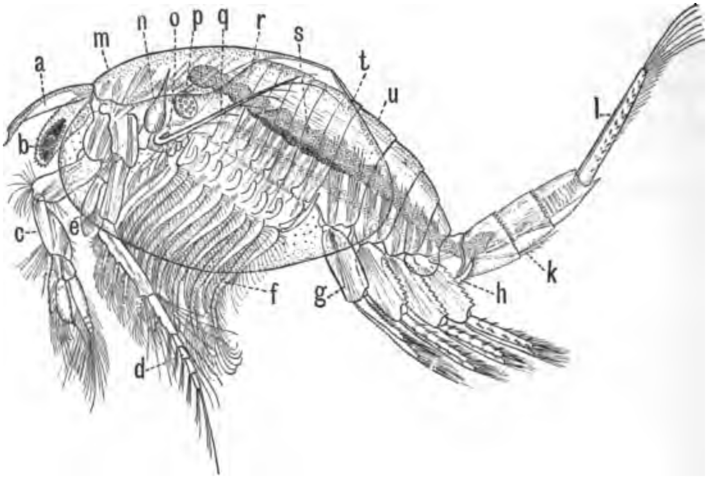

FIG. 126. *Paranebalia longipes*, Recent. (After Sars.) × 13. *a*, rostrum; *b*, eye; *c*, antennule; *d*, antenna; *e*, mandibular palp; *f*, last thoracic leg; *g*, first abdominal leg; *h*, *k*, rudimentary limbs of fifth and sixth abdominal segments; *l*, caudal fork; *m*, cephalic part of carapace; *n*, mandible; *o*, second maxilla; *p*, adductor muscle of carapace; *q*, first maxilla; *r*, first segment of thorax; *s*, ovary; *t*, last segment of thorax; *u*, first abdominal segment.

in possessing five segments in the head, and eight in the thorax; and in having nineteen pairs of appendages. They differ from the Malacostraca in the carapace being bivalved and not attached to the thorax; in the possession of a movable rostrum, of leaf-like thoracic legs, and of eight abdominal segments with a caudal fork, but no telson.

In the characters of the carapace and of the thoracic legs, and in the presence of a caudal fork, the Leptostraca resemble closely the Phyllopoda; but they differ from them in possessing a rostrum and a mandibular palp; in the long anterior antennæ, and in the clear separation of thorax from abdomen. Stalked eyes are found in some Phyllopoda and in many Malacostraca.

Some resemblance to the Copepoda is seen in the form of the body—especially the abdomen; in the long anterior antennæ and in the occurrence of a mandibular palp.

The Leptostraca are clearly generalised types, and are probably to be regarded as the last survivors of a primitive group of Crustacea. The Order is however without representatives in post-Triassic rocks; but a number of Crustacea, which closely resemble the living Leptostraca in the form of the body, are found in the Palæozoic formations; they differ, however, in being much larger and, in some cases also, in the possession of a telson,—in these respects they approach the typical Malacostraca. The appendages of these Palæozoic forms are very imperfectly known, and consequently it is difficult to determine their affinities satisfactorily. Masticatory organs, which resemble the gastric teeth of the lobster and cray-fish, have been found in some of the fossil forms and also occur in living Leptostraca. Some of the principal Palæozoic genera are described below.

Hymenocaris (fig. 127). Carapace semi-oval, smooth, not bivalved. Abdomen formed of eight segments and four, five, or six caudal spines. Appendages unknown. Lingula Flags. Ex. *H. vermicauda.*

Ceratiocaris. Carapace bivalved, often marked with striæ, oval, narrow in front, truncated behind and with a lanceolate rostrum in front. Body formed of fourteen or more segments, the first seven or more being

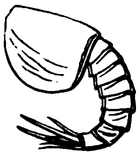

FIG. 127. *Hymenocaris vermicauda*, Lingula Flags. × ½.

covered by the carapace; telson long and pointed with two lateral spines. Tremadoc Beds to Carboniferous. Ex. *C. stygia*, *C. papilio*, Ludlow Beds.

Caryocaris (fig. 128). Carapace bivalved, pod-like, narrow, smooth, rounded at one end (probably the posterior), truncated at the other. Arenig Rocks. Ex. *C. wrighti.*

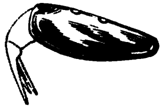

Fig. 128. *Caryocaris wrighti*, Arenig Rocks. Natural size. The abdomen has *not been found* attached to the carapace as shown above; some authors consider that the broad end of the carapace is anterior.

Dithyrocaris. Carapace large, bivalved, with a narrow anterior notch; rostrum unknown. Each valve semioval, truncated behind, with a median longitudinal ridge; another ridge at the dorsal margin where the valves join. Surface often with pits or granules. Exposed part of abdomen short, with a narrow, sharply-pointed telson bearing on each side a spine-like appendage. Devonian and Carboniferous. Ex. *D. colei*, Carboniferous.

Discinocaris. Carapace sub-circular, slightly convex, formed of one piece with a notch in front in which the triangular rostrum is placed. Surface with concentric linear ridges. Silurian. Ex. *D. browniana*, Llandovery.

Aptychopsis. Similar to the last, but carapace divided into two parts by a median suture which starts from the rostral notch. Silurian. Ex. *A. lapworthi*, Llandovery.

Distribution of the Leptostraca.

The three living genera are all marine. In Britain the earliest representative is *Hymenocaris*, found in the Lingula Flags; *Ceratiocaris* occurs in the Tremadoc Beds and ranges on to the Carboniferous, but is most abundant in the Silurian. *Caryocaris* is characteristic of the Arenig Rocks. *Aptychopsis* and *Discinocaris* occur in the Silurian. *Echinocaris* is found in the Devonian; and *Dithyrocaris* in the Carboniferous. One genus (*Aspidocaris*) has been recorded from the Trias.

ORDER II. THORACOSTRACA.

In this Order there is a cephalothorax formed by the fusion of the head with some or all of the segments of the thorax, and this is covered dorsally by a shield or carapace. There are thirteen segments in the head and thorax, six in the abdomen and a terminal telson. The eyes are compound and, except in the Cumacea, are placed on movable stalks.

The Thoracostraca include four sub-orders:—(1) Cumacea, (2) Schizopoda, (3) Stomatopoda, (4) Decapoda. The Cumacea are unknown in the fossil state.

SUB-ORDER II. SCHIZOPODA.

The Schizopods (fig. 129) are small, marine Crustacea in which the thorax is covered by a well-developed, but

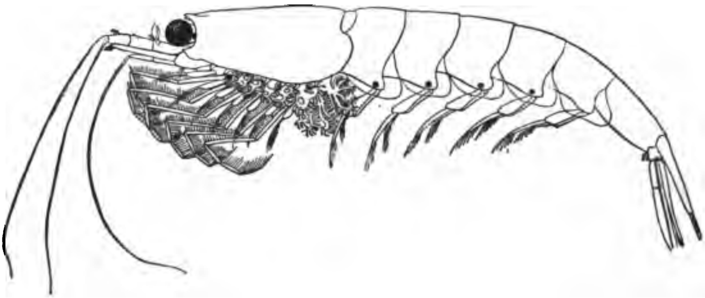

Fig. 129. A Recent Schizopod—*Nyctiphanes norvegica*. (After Watasé.) The black dots indicate the phosphorescent organs; the gills are seen between the cephalothoracic and abdominal appendages. Slightly magnified.

thin, cephalothoracic shield. The eight pairs of thoracic legs are biramous and are all similar in character, with the exception of the first two, which may serve as maxillipedes. The abdomen is long and slender.

This Sub-Order is not well represented in the fossil state. *Palæopalæmon* from the Upper Devonian and *Anthrapalæmon* from the Carboniferous are probably Schizopods, but have been thought by some writers to be Decapods (see p. 306). Other alleged representatives of the group have been recorded from the Coal Measures and the Solenhofen Limestone (Upper Jurassic).

SUB-ORDER III. STOMATOPODA.

In the Stomatopoda the body is long and flattened dorso-ventrally; the cephalothoracic shield is short and does not cover the three posterior thoracic segments. There are five pairs of maxillipedes. The three posterior segments of the thorax possess biramous appendages. The abdomen is much larger than the anterior portion of the body; its five anterior appendages bear gills, and the sixth pair of appendages form with the telson a strong swimming fin.

Squilla is the best known genus of this group. All the forms are marine and they live in shallow water. The Stomatopods are very rare as fossils. A few Crustacea found in the Carboniferous (*e.g. Necroscylla*) have been referred to this Sub-Order; but undoubted representatives, allied to the existing *Squilla*, occur in the Solenhofen Limestone (Upper Jurassic). *Squilla* itself has been found in the Chalk of Lebanon and in some of the Eocene formations (London Clay, etc.).

SUB-ORDER IV. DECAPODA.

The Decapoda include lobsters (fig. 130), cray-fishes, crabs, etc. The head, and in almost all cases all the segments of the thorax, are covered by a large and usually strong cephalothoracic shield (*a*—*c*); this is frequently marked out into an anterior and a posterior portion by a groove,—the *cervical suture* (*b*), the anterior part belonging to the head, the posterior to the thorax. The shield in front is produced into a spine, the rostrum (*a*). The gills are placed in a chamber formed by the downward prolongation of the cephalothoracic shield. The cephalothorax bears thirteen pairs of appendages, five belonging to the head, eight to the thorax. On the head there are (1) antennules, (2) antennæ, (3) mandibles, (4 and 5) maxillæ; the last three pairs serve as jaws. On the thorax the first three pairs of limbs, known as *maxillipedes*, function in locomotion and also in mastication; the posterior five pairs are the ambulatory limbs; they are uniramous and consist of seven joints, and some of them terminate in pincers or *chelæ*. The abdomen bears six, or

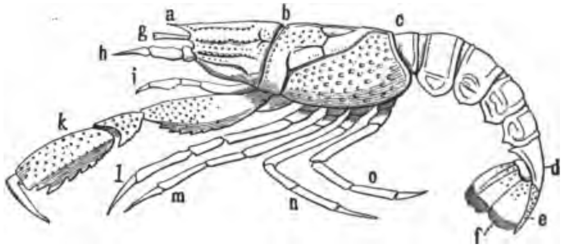

FIG. 130. *Glyphea regleyana*, Oxfordian. *a*—*c*, cephalothorax; *a*—*b*, head; *b*—*c*, thorax; *a*, rostrum; *c*—*e*, abdomen; *d*, last abdominal segment; *e*, telson; *f*, appendage of last abdominal segment; *g*, eye *h*—*o*, appendages of cephalothorax; *k*—*o*, ambulatory limbs. × ⅔.

fewer, pairs of small appendages. The name 'Decapoda' is taken from the five pairs of ambulatory limbs.

The Decapoda are divided into two sections:—(1) Macrura, (2) Brachyura.

Section 1. *Macrura.*

This section includes the lobsters, shrimps and crayfishes. The abdomen (fig. 130, *c*—*e*) is long, well developed, and provided with four or five pairs of appendages. There is a large caudal fin (*e*, *f*) formed by the telson and the appendages of the last abdominal segment.

Æger. Body laterally compressed. Abdomen long. Rostrum long, with small tubercles. Antennules nearly as stout, but not so long as the antennæ. Last maxillipedes long, with chelæ. Third pair of ambulatory legs longer than the others; the fourth and fifth pairs slender and flattened, with chelæ. Trias and Jurassic. Ex. *Æ. tipularius*, Solenhofen Limestone (Upper Jurassic).

Eryon. Cephalothorax flattened, broader than long, with a median dorsal ridge on the posterior part; the lateral margins usually dentate, and at the anterior third are deep notches. Rostrum short. The first four pairs of ambulatory limbs on the thorax bear chelæ, those of the anterior pair being larger than the others. Abdomen of about the same length as the cephalothorax; the first segment very short. Telson trigonal. Lias to Cretaceous. Ex. *E. antiquus*, Lias; *E. propinquus*, Solenhofen Limestone.

Glyphea (fig. 130). Cephalothorax ornamented with granules, provided with a median groove on the dorsal surface; rostrum short. In front of the cervical suture are several spiny or tuberculate parallel ridges which extend towards the anterior margin. Posterior to the cervical suture are generally two other grooves. The anterior pair of ambulatory limbs are much longer than the others. Abdomen long. Trias to Cretaceous. Ex. *G. regleyana*, Oxfordian; *G. tenuis*, Solenhofen Limestone (Upper Jurassic).

Meyeria. Cephalothorax greatly compressed laterally, with a sharp rostrum, and a deep V-shaped cervical suture; the posterior part of the cephalothorax covered with sharp granules. Abdomen semi-cylindrical, longer than the cephalothorax, and ornamented with rows of granules. Lower Cretaceous. Ex. *M. magna.*

Eryma. Body cylindrical. Cephalothorax covered with granules, with a median dorsal groove and a deep cervical suture. Behind the cervical suture are two nearly parallel grooves which unite at the sides. The three anterior pairs of ambulatory limbs with chelæ, the first pair being very large, the others small. Telson undivided. Lias to Upper Jurassic. Ex. *E. leptodactylina*, Solenhofen Limestone; *E. elegans*, Great Oolite, etc.

Enoploclytia. Body large, long, narrow; surface roughened with granules and tubercles. Cephalothorax elevated, narrowing in front, with a long rostrum. Behind the deep cervical suture are one or two nearly parallel furrows, from which lateral branches pass to the cervical suture. First pair of ambulatory legs very strong, with large chelæ having teeth on the inside of the fixed part; second and third pairs of legs slender, also with chelæ. Telson large, subtrigonal. Upper Cretaceous. Ex. *E. leachi*, Chalk.

Hoploparia. Body slightly compressed. Cephalothorax covered with fine granules. Rostrum very narrow, long, sharp and not dentate. Cervical suture deep, not reaching the margins of the carapace; in front of the cervical suture is a λ-shaped groove. The two anterior pairs of ambulatory limbs large, provided with chelæ. Abdomen sub-cylindrical. Lower Cretaceous to Eocene. Ex. *H. longimana*, Lower Greensand.

Section 2. Brachyura.

This section includes the crabs. The abdomen is short and small; it is curved up underneath the thorax, and bears from one to four pairs of appendages. There is no caudal fin. The cephalothorax is often broad.

Dromia. Cephalothorax oval or rounded, very convex, with the entire surface punctate; anterior part with pointed elevations, posterior third with irregular ridges; divided into regions by two transverse grooves. Rostrum short, triangular. Orbital cavity very deep. First pair of ambulatory legs strong, with large chelæ; second and third pairs short; fourth and fifth slender. Abdomen of six segments in both sexes. Eocene to present day. Ex. *D. lamarcki*, London Clay.

Palæocorystes. Cephalothorax much longer than broad, tapering posteriorly, anterior border not dentate; rostrum short. Orbital cavities large with two small fissures. Cervical suture well defined. The five anterior segments of the abdomen short, the sixth quadrangular. Gault and Eocene. Ex. *P. stokesi*, Gault.

Eucorystes. Cephalothorax trapezoidal; anterior part with tortuous, band-like elevations; posterior part smooth or finely granular. Cambridge Greensand. Ex. *E. carteri*.

Necrocarcinus. Cephalothorax rounded, separated into regions by distinct grooves, ornamented with a few prominent tubercles. Rostrum triangular. Orbital cavities rounded, open above, with two small fissures. Gault to Chalk. Ex. *N. bechei*, Cambridge Greensand.

Xanthopsis. Cephalothorax rounded, convex, surface punctate, the posterior portion with rounded elevations; the frontal border with four, and the anterior-laterals with one to three, tooth-like processes. Orbital cavities deep, without fissures. Chelæ unequal. Abdomen of the male narrow and formed of five segments, owing to the fusion of the third, fourth, and fifth segments. Abdomen of female broad, composed of seven segments. Eocene. Ex. *X. leachi*, London Clay.

Distribution of the Decapoda.

Most of the Decapoda are marine, the larger number living in shallow water. The earliest undoubted examples of the Macrura (*Pemphix*) appear in the Muschelkalk, but a few genera found in the Upper Palæozoic formations may belong to this section; they are, however, regarded by recent writers as more probably Schizopods (p. 302). The section becomes abundant in the Jurassic, where, amongst others, the genera *Glyphea, Eryon, Mecochirus, Æger*, and *Eryma* are found. In the Cretaceous, *Enoploclytia, Hoploparia* and *Meyeria* occur. Comparatively few forms are found in the Tertiary deposits.

A few examples found in the Upper Palæozoic rocks may belong to the Brachyura, but at present they are only imperfectly known; the group is represented by two or three genera (*Prosopon, Palæinachus*) in the Jurassic; in the Cretaceous by *Palæocorystes, Eucorystes, Necrocarcinus* and several others; in the Eocene numerous forms occur, *Xanthopsis* and *Dromia* being common. The section attains its maximum at the present day.

ORDER III. ARTHROSTRACA.

There is no cephalothoracic shield. The first (sometimes also the second) thoracic segment fuses with the head and bears maxillipedes. The remaining seven (rarely fewer) thoracic segments are free and bear walking legs. The abdomen has six pairs of appendages. The eyes are sessile. There are two Sub-orders:—(1) Amphipoda, (2) Isopoda.

SUB-ORDER I. AMPHIPODA.

The Amphipods (*e.g. Gammarus, Talitrus*) are usually of small size, and the body is compressed from side to side. There are six or seven free segments in the thorax, the appendages of which bear the gills. The abdomen is usually elongated and carries six pairs of appendages; the three anterior serve for swimming, the three posterior for jumping.

Some of the Amphipods are marine, others live in fresh water. The marine forms have a wide distribution, and are very numerous, especially in shallow water. The fossil forms are rare; *Necrogammarus* from the Lower Ludlow rocks of Leintwardine is probably an Amphipod; others—but of which the systematic position is a little uncertain—have been recorded from the Carboniferous and Permian; those found in the Tertiary formations belong mainly to genera which are still existing (*e.g.* *Gammarus* from the Miocene).

SUB-ORDER II. ISOPODA.

The body is flattened dorso-ventrally (*i.e.* from above downwards). In the thorax there are seven free segments, each with a pair of ambulatory appendages. The abdomen is often short, and is formed of six segments (frequently fused) and a telson; some of its appendages function as gills.

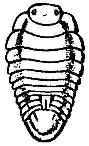

FIG. 131. *Archæoniscus brodiei*, from the Purbeck Beds. Slightly reduced.

Many Isopods are marine, others are found in fresh water, whilst a few live on land (*e.g.* the wood-louse, *Oniscus asellus*). The fossil forms are rare. An imperfect specimen, from the Old Red Sandstone of Herefordshire, described under the name of *Præarcturus gigas*, probably belongs to this group. *Arthropleura* occurs in the Coal Measures; *Cyclosphæroma* in the Great Oolite and Purbeckian; *Archæoniscus* in the Purbeckian (fig. 131); *Palæga* in the Cambridge Greensand, the Lower Chalk, and Foreign Tertiary; and *Eosphæroma* and other genera in the Oligocene.

CLASS III. MYRIAPODA.

The Myriapoda include the millipedes, centipedes, and allied forms. The body consists of a distinctly-marked head, followed by segments which are similar in form and size, so that, externally, the limits of the thorax and abdomen cannot be defined; the segments are usually numerous. The head bears one pair of antennæ; and also mandibles and maxillæ. The segments behind the head (except the last) bear in some cases one, in others two, pairs of legs each; in the latter the segments are really double. The Myriapods breathe by means of tracheæ.

In the fossil state Myriapods are rare. Existing forms have been divided into two Orders[1]:—(1) the *Chilopoda*, or centipedes, (2) the *Diplopoda*, or millipedes. The first undoubted representatives of the Chilopoda occur in the amber found in the Oligocene beds of Prussia; the Diplopoda have also been found mainly in this amber, but one form, which perhaps belongs to this Order, was discovered in the Cretaceous rocks of Greenland. The Palæozoic Myriapods differ considerably from the later representatives of the group and are regarded as constituting two distinct Orders which are confined to the Palæozoic formations. The earliest examples belong to the genera *Kampecaris* and *Archidesmus*, and occur in the Old Red Sandstone of Scotland; a larger number of forms (*e.g. Xylobius, Euphoberia*) are found in the Carboniferous, and some are present in the Permian rocks.

CLASS IV. INSECTA.

The body of an insect can be separated into head, thorax, and abdomen. The head is formed of fused

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[1] These are regarded as two distinct Classes by Lankester.

segments; it bears four pairs of appendages—one pair of antennæ, one of mandibles, and two of maxillæ. In the thorax there are three segments, each bearing one pair of legs; the second and third segments usually carry a pair of wings on their dorsal surfaces. The abdomen is composed of several (commonly ten) segments, which do not bear limbs. Insects breathe by means of tracheæ.

The earliest Insects at present known are *Protocimex silurica* from the Ordovician of Sweden, and *Palæoblattina douvillei* found in the Silurian rocks of France. Others occur in the Devonian of North America. In the Coal Measures of some districts the group is represented by a considerable variety of forms. Remains of insects have been found at many horizons in the Mesozoic and Cainozoic formations; in England they are not uncommon in certain divisions of the Lias, the Purbeck, the Wealden, and the Bembridge Beds. They are well represented in the Solenhofen Limestone (Upper Jurassic) of Bavaria, in the Miocene of Oeningen in Switzerland, and particularly so in the amber of the Oligocene beds of Prussia.

The Insects found in the Palæozoic formations are considered by Scudder to be more generalised than the later forms. He regards them as constituting a distinct Order; Brongniart, however, by a careful study of better-preserved specimens, has shown that these early insects can all be placed in the Orders adopted for existing forms, but that in Palæozoic times the Orders were less sharply separated than at the present day.

The Insecta include an enormous number of forms, and the specimens found fossil are usually very imperfectly preserved, so that nothing more than a brief sketch of the distribution of the chief groups can be attempted here.

The Class is divided into eight Orders:—

ORDER I. APTERA.

Examples of this Order (which contains small wingless forms such as *Lepisma,* the silver-fish) occur in the Coal Measures of Commentry, and several have been found in amber from the Oligocene rocks.

ORDER II. ORTHOPTERA.

The Forficulidæ (earwigs) occur first in the Lias; others have been found in the Oligocene amber but they are not common. Examples of the Blattidæ (cockroaches) are found in the Trias and are fairly common in the Jurassic; the Tertiary forms occur mainly in the Oligocene amber. *Palæoblattina,* from the Silurian, has been referred to the Blattidæ, but its affinities have not yet been definitely proved. Ancestors of the Locustidæ (locusts) and the Acridiidæ (grasshoppers) are known first in the Coal Measures; a few forms belonging to these families have been obtained from the Jurassic and Tertiary deposits. The Gryllidæ (crickets) occur in the Lias, and several forms have been found in the Tertiary rocks.

ORDER III. NEUROPTERA.

The earliest examples of this Order occur in the Devonian: in the Coal Measures quite a variety of forms are met with. Termitidæ (white ants) have been discovered in the Lias, and many examples have been found in Tertiary rocks. Forms allied to the Ephemeridæ (may-flies) are present in the Coal Measures; others occur in the Solenhofen Limestone and in the Oligocene amber. The Libellulidæ (dragonflies) have representatives in the Coal Measures, the Lias, the Solenhofen Limestone, and the

Wealden; and some occur in the Tertiary formations. A few examples of the Phryganidæ (caddis-flies) are known from the Mesozoic rocks, and various forms exist in the Tertiary beds.

ORDER IV. LEPIDOPTERA.

Butterflies and moths are very rare as fossils. A few have been recorded from the Jurassic rocks; they are better represented, although still very uncommon, in the Tertiary beds.

ORDER V. COLEOPTERA.

The Coleoptera (beetles) first appear in the Trias; they are more numerous in the Jurassic, and are well represented in some of the Tertiary beds.

ORDER VI. HEMIPTERA.

Protocimex, from the Ordovician, probably belongs to this Order. Other forms have been recorded from the Upper Palæozoic rocks. Examples of the Aphididæ (plant-lice) are found in the Wealden strata, and there are many forms in the Tertiary. The Cicadidæ occur in the Lias and are abundant in the Tertiary. The Notonectidæ (water-bugs) appear in the Tertiary rocks.

ORDER VII. DIPTERA.

The Diptera include flies, fleas, gnats, and mosquitoes. A few forms are found in the Lias, the Solenhofen Limestone, and the Purbeck Beds; the Order is represented by numerous forms in the Tertiary strata.

ORDER VIII. HYMENOPTERA.

This Order includes the ants, bees, and wasps. One form has been found in the Lias, a few occur in the Solenhofen Limestone and the Purbeck Beds; a larger number are met with in the Tertiary rocks.

CLASS V. ARACHNIDA.

Scorpions, spiders, and mites are common forms of the Arachnida. In the members of this Class the anterior segments of the body are fused together, forming a *prosoma* or cephalothorax. This region usually bears six pairs of appendages; antennæ are absent; the first and second pairs of appendages—known as *cheliceræ* and *pedipalpi*—end in chelæ, and serve mainly as jaws; the four remaining pairs are long limbs which are used for locomotion and to some extent in mastication, and are placed behind the mouth. The abdomen may or may not be segmented; in some groups it is divided into an anterior and a posterior region (*mesosoma* and *metasoma*). The appendages of the abdomen are never in the form of locomotory limbs. The Arachnids breathe by means of lung-books, tracheæ, or branchiæ.

The Class is divided into nine Orders:—

ORDER I. XIPHOSURA[1].

The only living representative of the Xiphosura is *Limulus*, the king-crab (figs. 132, 133), found on the eastern shores of North America and Asia, and in the Malay Archipelago. The body of *Limulus* consists of a cephalothorax or prosoma (fig. 132 *A*) and an abdomen (*B*) which bears a long, movable tail spine (*C*).

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[1] Some authors include the Xiphosura and the Eurypterida in one group—the *Merostomata*.

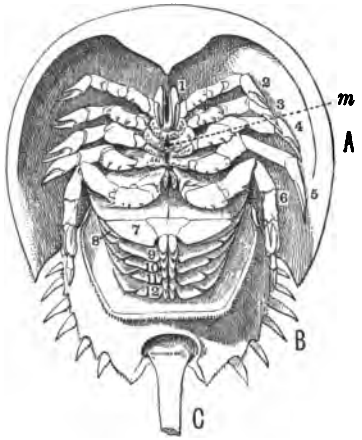

Fig. 132. *Limulus polyphemus*, Recent. *A*, cephalothorax (prosoma). *B*, abdomen. *C*, portion of the caudal spine. 1—6, appendages of the cephalothorax; 1, chelicerae, 2, pedipalpi; 3—6, ambulatory legs; 7—12, appendages of the abdomen; 7, operculum; 8—12, lamellae bearing gills. *m*, mouth. Reduced.

The cephalothorax is covered dorsally by a large crescentic or nearly semicircular carapace (fig. 133, 1), which is very convex above and carries on its upper surface two pairs of eyes, one compound (5), the other simple and termed *ocelli* (4). The compound eyes are placed near the middle of the lateral parts of the cephalothorax; the simple eyes are close together near the anterior margin. The abdomen is more or less quadrate in outline and is movably articulated with the cephalothorax; both have two longitudinal furrows on the dorsal surface, dividing a narrow axial part from a broad lateral portion on each side. The abdomen is composed of six fused segments, the segmentation being shown by grooves on the dorsal surface; but a small posterior part of it is without grooves and is thought to represent the metasoma of the scorpion. The abdominal shield bears movable spines on each side.

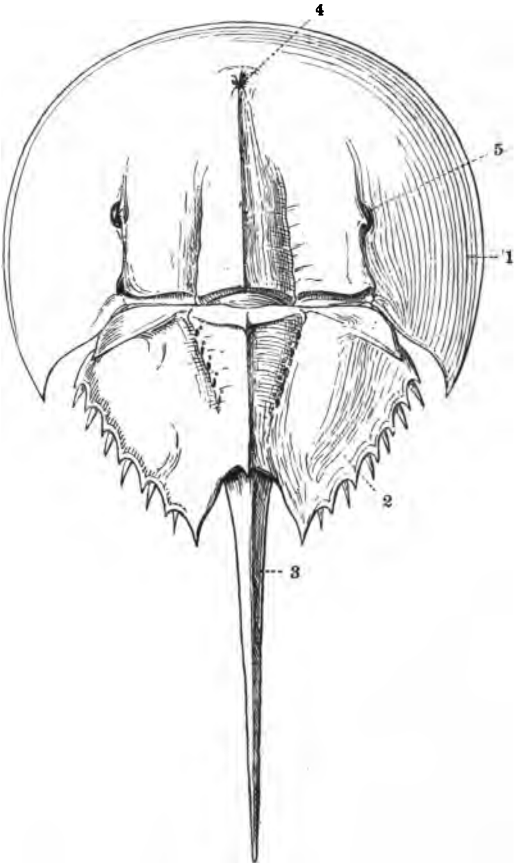

FIG. 133. *Limulus polyphemus*, Recent. Dorsal view. 1, carapace covering prosoma (cephalothorax); 2, abdominal shield; 3, tail-spine; 4, ocelli; 5, lateral eyes. (From Shipley and MacBride.) × ½.

The cephalothorax carries six pairs of appendages on its under surface; the anterior pair (fig. 132, 1) (*cheliceræ*) only are placed in front of the mouth and are small, three-jointed appendages with chelæ. The other five pairs (2—6) are the long, six-jointed walking-legs and are placed at the sides of the mouth; most of them end in chelæ and their basal joints (except in the sixth pair) function in mastication. The abdomen carries six pairs of appendages; the anterior pair, forming what is known as the *operculum* (7), are plate-like and have the genital openings on their posterior surfaces. The operculum covers the remaining five pairs of appendages, which are also plate-like and bear the gills on their posterior surfaces.

From the account given above it will be noticed that *Limulus* resembles the scorpions in several respects. In both, the front region of the body (prosoma or cephalothorax) consists of six fused segments, covered dorsally by a carapace which bears a pair of simple eyes and also a pair of groups of eyes ('compound eyes'). The mesosoma of *Limulus* differs from that of the scorpions in having the segments fused, and the metasoma of the former is much reduced; but both agree in possessing a tail spine behind the anus. In both cases the prosoma bears six pairs of appendages which are very similar in form and position. In the mesosoma of both the genital operculum represents the first pair of appendages; the second pair are the pectines of the scorpions, and the first plate which bears gill-books in *Limulus.* The next four segments carry lung-books in the scorpions and gill-books in *Limulus.* From these and other characters it is concluded that *Limulus* is allied to the Scorpionida rather than to the Crustacea as was formerly supposed. The differences between the mesosoma and metasoma of *Limulus* and the scorpions are, to some extent, bridged over by some of the Palæozoic Xiphosura described below.

Limulus appears first in the Trias; it is common in the Solenhofen Limestone and is also represented in the Oligocene. In the Palæozoic deposits—from Silurian[1] to Carboniferous—several other Xiphosura occur; some of these (fig. 134) differ from *Limulus* in having some or all of the abdominal segments free, and also in having a post-abdomen (metasoma) clearly separable from a pre-abdomen (mesosoma). In these respects they approach both the Eurypterida and the Scorpionida. A few forms show indications of sutures similar to the facial sutures of Trilobites. The examples found in the Coal Measures may perhaps have lived in fresh water.

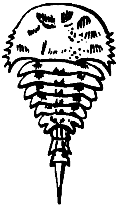

FIG. 134. *Hemiaspis limuloides*, from the Lower Ludlow Beds. × ½.

Belinurus. Form similar to *Limulus*. Cephalothorax semicircular, with a flat border and spines from the angles; central part raised. Pre-abdomen of five free segments, with the lateral parts produced into spines. Post-abdomen small, formed of three fused segments with a long caudal spine. Coal Measures. Ex. *B. reginæ*.

Prestwichia. Cephalothorax similar to *Belinurus*. Abdominal segments (probably seven) fused, with a flat marginal part and a short caudal spine. Coal Measures. Ex. *P. rotundata*.

Hemiaspis (fig. 134). Cephalothorax semicircular, with spines at the external margin and angles; central part raised. Pre-abdomen of six free segments; post-abdomen much narrower, of three segments and a long caudal spine. Silurian. Ex. *H. limuloides*.

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[1] *Aglaspis*, from the Cambrian of Wisconsin, is referred by some authors to the Trilobita, by others to the Xiphosura.

Bunodes. Similar to *Hemiaspis*. Cephalothorax without spines. Pre-abdomen with broad axial part. Post-abdomen of four segments. Silurian. Ex. *B. lunula.*

Neolimulus. Cephalothorax very broad, with ocelli and compound eyes; a suture passes from the angles to the compound eyes. Abdomen with eight or more free segments. Silurian. Ex. *N. falcatus.*

Distribution of the Xiphosura.

Fossil Xiphosura are rare, except in the Solenhofen Limestone (Upper Jurassic). The chief genera are:

Silurian. *Hemiaspis, Neolimulus, Bunodes, Pseudoniscus.*
Carboniferous. *Belinurus, Prestwichia.*
Trias and Jurassic. *Limulus.*

ORDER II. EURYPTERIDA.

The Eurypterids are found only in the Palæozoic rocks and are remarkable for the large size which they usually attain; one form (*Pterygotus anglicus*) reaches a length of six feet and is the largest Arthropod known. The Eurypterids have a scorpion-like appearance; but, unlike the scorpions, they were all aquatic animals, and, with the possible exception of forms found in the Coal Measures, all marine. The body is protected by a chitinous skeleton (fig. 135) which is covered by small scale-like markings.

The six anterior segments are fused together and form a cephalothorax or prosoma, which is usually quadrate or semicircular in outline. The carapace or shield, which covers the dorsal surface of the cephalothorax, bears a pair of simple eyes (ocelli) near its centre (fig. 135, *e*), and also two groups of eyes—one at each of the outer front margins or near those margins (*d*).

Behind the cephalothorax come the twelve free and movable segments of the abdomen; in *Pterygotus* (fig.

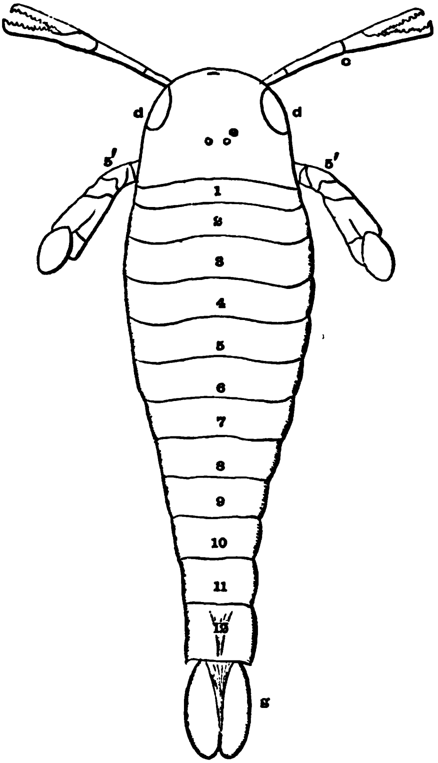

FIG. 135. Dorsal surface of *Pterygotus osiliensis*, from the Upper Silurian, Rootziküll. *c*, first pair of appendages; *d*, compound eyes; *e*, ocelli; *g*, telson; 5′, sixth pair of appendages; 1—7, segments of the prosoma or pre-abdomen; 8—12, segments of the metasoma or post-abdomen. Reduced. (After Schmidt.)

135) the width of these segments gradually decreases in passing from the anterior to the posterior end, but in most

other cases (fig. 137) they are divisible into two groups; the seven anterior are broad, forming the pre-abdomen or

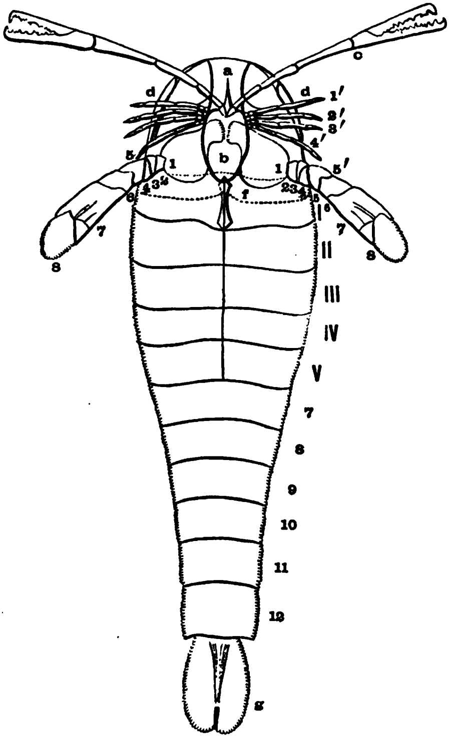

Fig. 136. Ventral surface of *Pterygotus osiliensis*, from the Upper Silurian, Rootziküll. *a*, epistome; *b*, metastoma; *c*, first pair of appendages; *d*, compound eyes; *f*, operculum; *g*, telson; 1′–5′, second to sixth pairs of appendages; I.–V., 7, ventral plates of the prosoma or pre-abdomen; 8—12, segments of the metasoma or post-abdomen. Reduced. (After Schmidt.)

mesosoma (fig. 137, VII.—XIII.), the five posterior are narrow, forming the post-abdomen or metasoma (XIV.—XVIII.), at the end of which is the telson (*g*); this is sometimes (*Eurypterus*) spine-like, but usually in the form of an oval plate which may be produced into a median spine as in *Slimonia*, or divided at the end as in some species of *Pterygotus*. Each segment of the prosoma (pre-abdomen) is covered by a dorsal shield and a ventral plate, but in the metasoma (post-abdomen) each segment is surrounded by a continuous chitinous sheath.

The mouth is on the under surface of the cephalothorax (fig. 136). In front of the mouth there is one pair of appendages only (*c*), which end in chelæ and are usually small. The other five pairs of appendages (1′—5′) are placed at the sides of and behind the mouth; they consist of from six to eight joints each, and are sometimes chelate; they functioned in locomotion, and also in mastication since the basal joints are provided with tooth-like processes; the posterior pair (5′) (except in *Stylonurus*) are very much larger than the others and have a very large basal joint. Placed just behind the mouth, in the median line, is an oval or heart-shaped plate—the *metastoma* (*b*). Immediately in front of the mouth is another plate, the *epistoma* (*a*).

The six segments of the prosoma are covered on the ventral surface by five plate-like structures (I.—V.) beneath which are the leaf-like gills (fig. 137, *c*). The first plate, known as the operculum, is divided in the middle and has a median process; it corresponds with the genital operculum of *Limulus*. The segments of the metasoma or post-abdomen (fig. 136, 8—12) are protected by continuous chitinous rings and bear no appendages.

In many respects the Eurypterids resemble both the Scorpionida and the Xiphosura. With the former they agree in the form of the body; in the number of segments and their arrangement into three regions; and in the characters of the two pairs of eyes. In both Eurypterids and Scorpions the prosoma bears six pairs of appendages which are similar in position and in general form; but in the Eurypterids the number of joints in the walking legs varies, and the basal segments of all assist in mastication; the last leg is also very much larger relatively than in the scorpions. A genital operculum occurs in both, but is much larger in the Eurypterids than in the Scorpions. The pectines are absent in the Eurypterids, except in *Glyptoscorpius* from the Carboniferous—and this form is regarded by some authors as more probably a scorpion than a Eurypterid. The lung-books of the scorpions are represented by the leaf-like gills of the Eurypterids. In both groups the metasoma is without appendages and ends in a telson or tail-spine. The differences between the Eurypterids and recent scorpions are to some extent bridged over by *Palæophonus,* a Silurian scorpion (see p. 327). One of the most characteristic features of the Eurypterids is the large metastoma.

Limulus agrees with the Eurypterids in having the carapace covering the prosoma, and in the characters of the two pairs of eyes, but differs in that the segments behind the prosoma are fused together. The appendages of the prosoma agree with those of Eurypterids in number and position, and are similar in structure, but the number of joints differs, and in the Eurypterids the first pair only of appendages end in chelæ. The genital operculum and the gill-books are similar in both cases.

Eurypterus. Cephalothoracic shield quadrate, the anterior angles rounded; the compound eyes are not at the margin, but a little in front of the median lateral point on each side. The telson is long, narrow, and pointed. The pre-oral appendages are small and chelate; the second, third and fourth pairs of appendages consist of six or seven joints and bear spines; the fifth are longer than the preceding and without spines; and the sixth pair are much longer and also larger. The metastoma is oval. Lower Ludlow to Carboniferous. Ex. *E. scorpioides*, *E. fischeri*, Upper Silurian; *E. scouleri*, Carboniferous.

Stylonurus. Form similar to *Eurypterus*, but the two posterior pairs of appendages are very long and slender. Upper Silurian and Old Red Sandstone. Ex. *S. powriei*, same range.

Pterygotus (figs. 135, 136). Cephalothoracic shield rounded in front; the compound eyes are placed at the margins. The telson is oval and either bilobed or pointed at its extremity. The pre-oral appendages are long and chelate; the sixth pair long and stout. Metastoma oval. The examples of this genus are often of enormous size, *P. anglicus* sometimes reaching a length of nearly six feet. Lower Ludlow to Old Red Sandstone. Ex. *P. anglicus*, Old Red Sandstone; *P. bilobus*, Upper Silurian.

Slimonia (fig. 137). Cephalothoracic shield quadrate; the compound eyes at the anterior angles. Segments of the mesosoma (pre-abdomen) much larger than those of the metasoma (post-abdomen). The telson is oval, ending in a

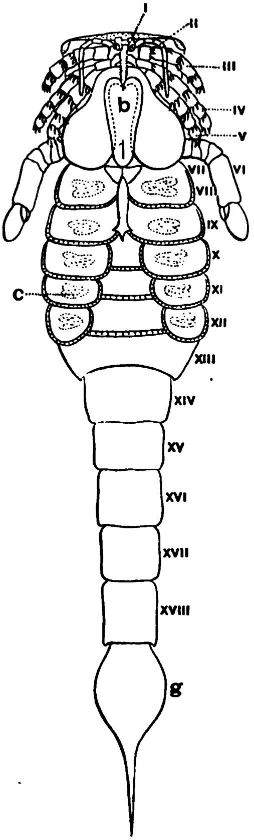

FIG. 137. *Slimonia*. Restoration of the under surface by M. Laurie. *b*, metastoma; *c*, leaf-like gills seen through the ventral plates of the abdomen; *g*, telson; I.—VI. appendages of the cephalothorax; VII.—XIII., segments of the mesosoma or pre-abdomen; XIV.—XVIII., segments of the metasoma or post-abdomen. Reduced.

point. Metastoma heart-shaped. The pre-oral appendages (chelicerae) are small and chelate; the second pair of appendages are slender, composed of six joints, and are not chelate. The third, fourth, and fifth pairs are seven-jointed, and similar in size and form. The sixth pair are longer and have a very large basal joint. Upper Ludlow and Passage beds. Ex. *S. acuminata*, uppermost beds of the Silurian.

Distribution of the Eurypterida.

This Order ranges from the Cambrian to the Permian, but is most abundant in the Upper Silurian and the Old Red Sandstone. The only form known from the Cambrian is *Strabops*, from Missouri. The chief genera in the Silurian and Old Red Sandstone are *Eurypterus*, *Stylonurus*, *Pterygotus* and *Slimonia*; and in the Carboniferous *Eurypterus*.

ORDER III. SCORPIONIDA.

The scorpions (fig. 138) have a long, narrow body, in which three regions are clearly marked. The front, known as the *prosoma* or cephalothorax, consists of six fused segments, covered dorsally by a carapace which bears a pair of simple eyes (ocelli) near its centre, and a group of simple eyes at each of the two outer front margins. The middle region of the body—the *mesosoma* or *pre-abdomen* (7—13)—is formed of seven free segments, which are short and broad; the chitinous sheath of each segment consists of a dorsal plate or *tergum* and a ventral plate or *sternum*. The posterior portion of the body is the *metasoma* or *post-abdomen* (14), and is formed of five narrow segments, each being encased in a complete chitinous cylinder; at the end of the last segment is the tail-spine or *telson* (15), which bears the poison glands. The anal opening is on the last segment.

The prosoma bears six pairs of appendages:—(1) the

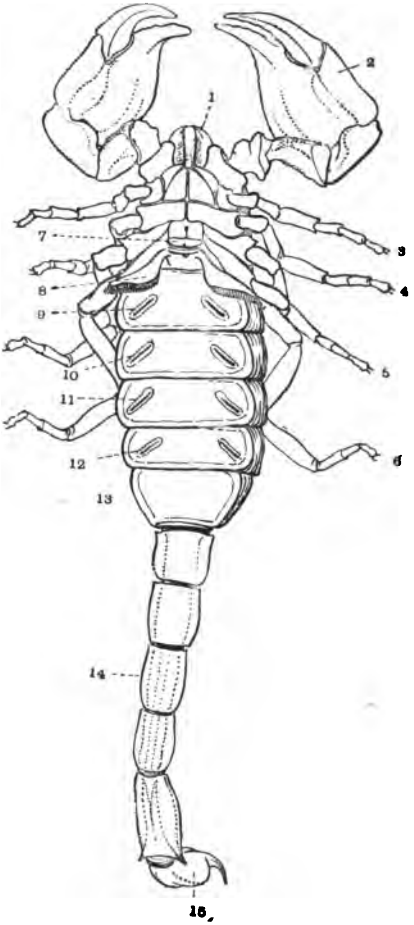

FIG. 138. Ventral view of an Indian Scorpion, *Scorpio swammerdami.* 1, chelicera; 2, pedipalp; 3, 4, 5, 6, walking-legs; 7, genital operculum; 8, pectines; 9, 10, 11, 12, the four right stigmata leading to the lung-books; 13, last segment of mesosoma; 14, third segment of metasoma; 15, telson. (From Shipley and MacBride.) × ⅔.

chelicerœ (fig. 138, 1) are small three-jointed limbs with chelæ, placed just in front of the mouth; (2) the *pedipalps* (2) are the largest appendages and are placed at the sides of the mouth; they consist of six joints, ending with chelæ, and the basal joints function in mastication; (3—6) next come four pairs of seven-jointed walking legs which end in claws, instead of chelæ; the basal joints of the third and fourth pairs assist in mastication.

On the seventh segment of the body (the *first* of the mesosoma) there is a small rounded plate—the *genital operculum* (fig. 138, 7). The eighth segment bears the *pectines* (8), which consist of a stem with a row of short processes like the teeth of a comb. On segments nine to thirteen, there are, in the adult, no proper appendages; but a pair of oblique, slit-like openings—the *stigmata*, leading into the lung-books, occur on each of the segments nine to twelve[1]. The metasoma (segments 14 to 19) has no appendages.

Although this Order is of great antiquity, it has but few fossil representatives. *Palœophonus* occurs in the Silurian rocks of Gothland and Lanarkshire; *Proscorpius* in the Silurian of North America. *Eoscorpius* is found in the Carboniferous of Scotland, the Midlands, and North America. One form (*Tityus*) is known from the Oligocene beds.

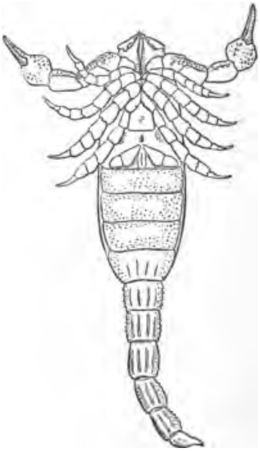

FIG. 139. *Palœophonus caledonicus* from the Upper Silurian of Lesmahago, Lanarkshire. Restoration of ventral surface by R. I. Pocock. × 1½.

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[1] Segment 13, which has no stigmata, is regarded by some authors as the first segment of the metasoma.

Eoscorpius does not differ in any important respect from living scorpions, and appears to have been quite as highly organised. *Palæophonus,* however, is rather more primitive in some of its characters; the walking legs consist of nearly equal-sized joints and seem to be without claws; the basal joints of all these legs could serve to some extent as jaws and in this respect resemble the walking legs of *Limulus* and the Eurypterida. *Palæophonus,* unlike later scorpions, seems to have been aquatic, since it is found associated with marine fossils, and moreover, stigmata appear to have been absent—it probably therefore breathed by means of branchial lamellæ instead of lung-books.

The remaining Orders of the Arachnida are but poorly represented in the fossil state; their general distribution is briefly indicated below.

ORDER IV. PSEUDOSCORPIONIDA.

This Order includes the book-scorpions (*Chelifer cancroides*) and others. Various forms, belonging to existing genera, occur in the Oligocene amber, *e.g. Chelifer, Chernes.*

ORDER V. PEDIPALPI.

The scorpion-spiders are represented by *Geralinura* in the Carboniferous, and by *Phrynus* in the Tertiary rocks.

ORDER VI. ARANEIDA.

Spiders belonging to the genera *Protolycosa* and *Palaranea* are found in the Coal Measures. In the Oligocene—especially in the amber of Prussia—a large number of forms occur.

ORDER VII. PHALANGIDA (or Opilionina).

The examples of this Order are commonly known as 'harvest-men'; they have only yet been found fossil in the Oligocene amber.

ORDER VIII. ACARINA.

This Order comprises the mites and ticks. Various forms of mites, belonging chiefly to living genera, occur in the Oligocene amber.

ORDER IX. ANTHRACOMARTI.

The Anthracomarti are found in the Carboniferous rocks only, and are related to the Pedipalpi and Pseudoscorpionida. Some of the principal genera are *Architarbus, Anthracomartus, Kreischeria, Eophrynus.*

LIST OF PALÆONTOLOGICAL WORKS.

ABBREVIATIONS.

A. J. S.	American Journal of Science.
A. M. N. H.	Annals and Magazine of Natural History.
G. M.	Geological Magazine.
Q. J. G. S.	Quarterly Journal of the Geological Society.

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